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Optical, chemical, and biological oceanographic conditions on the Newfoundland and Labrador Shelf during 2013

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Seasonal cycles in temperature and salinity properties at Station 27 (S27) have shifted with warm and fresh conditions persisting well into winter in recent years. Advancing seasonal cycles in physical conditions observed in recent years at S27 appear to result in earlier spring drawdown and delayed recycling of macronutrient levels of silicate and nitrate that has traditionally occurred in the early autumn. Consequently, seasonally-adjusted annual anomalies of shallow and deep inventories of these macro-nutrients at S27 and across the sections are well below the annual climatology since 2009-10 and in 2013, were approaching 3 standard deviation units below normal. In general, inventories of chlorophyll *a* (proxy for phytoplankton standing stock) at S27 and across sections remain below normal in recent years and were at the lowest level observed in the time-series at S27 in 2013. Overall, the amplitude (peak intensity) and magnitude (integrated chl*a* biomass) of the spring bloom was below normal across most of the Newfoundland and Labrador (NL) sub-regions in 2013 compared to the climatology (1999-2010). The initiation of the spring bloom was delayed on the southern Labrador and northeast Shelf resulting in reduced duration. The other sub-regions showed consistent timing indices with the exception of Hibernia that initiated substantially earlier resulting in a long duration bloom. The abundance of *Oithona similis, Pseudocalanus* sp. and *Triconia* sp. is at or near record levels of abundance from the Bonavista Bay to the southern Grand Banks sections. The abundance of *Calanus glacialis* and *Calanus hyperboreus* has shown long-term declines in abundance on the Flemish Cap and southeast Grand Bank starting in 2001, and shorter term declines on the Bonavista Bay and Seal Island section since 2009. Copepodite biomass at S27 in 2011-13, based on the abundance of 8 dominant taxa, has demonstrated a consistent decline over time to a record low value in 2013 since the record high levels observed in 2009. Analysis of seasonal patterns in abundance reveals dramatic shifts in phenology of ecologically-important copepod species such as *C. finmarchicus* and *Pseudocalanus* sp. have occurred at S27 starting approximately in 2005, when the fall cohorts increase in relative abundance. The overall pattern of variation among the three trophic levels surveyed in this report (nutrients, phytoplankton biomass, and zooplankton abundance) does not reveal any clear association among trophic levels but consistency in some trends may be starting to provide new insights into trophic relationships.

Conditions océanographiques biologiques, chimiques et optiques sur la plate-forme continentale de Terre-Neuve-et-Labrador en 2013

RÉSUMÉ

Ces dernières années, les cycles saisonniers de température et de salinité à la station 27 (S27) se sont déplacés, prolongeant les conditions chaudes et fraîches jusqu'en hiver. Le devancement des cycles saisonniers dans les conditions physiques observées dans les dernières années semble avoir entraîné un devancement du rabattement printanier et un retard du recyclage des niveaux de macronutriments (silicate et nitrate), qui, auparavant, avait lieu en début d'automne. Résultat, les anomalies annuelles ajustées pour les variations saisonnières des couches de surface et profonde de ces macronutriments à la S27, pour toutes les sections, sont bien en dessous de la normale climatologique depuis 2009-2010; en 2013, elles approchaient 3 écarts-types sous la normale. En général, les inventaires de chlorophylle *a* (une approximation du stock actuel de phytoplancton) à la S27 et dans toutes les sections sont restés sous la normale ces dernières années et ont atteint leur plus bas niveau de toute la série temporelle à la S27 en 2013. Dans l'ensemble, l'amplitude (intensité maximale) et la magnitude (biomasse intégrée de chlorophylle *a*) de la floraison printanière en 2013 étaient en dessous de la normale dans presque toutes les sous-régions du plateau de Terre-Neuve par rapport à la moyenne climatologique (1999-2010). Le début de la floraison printanière a été retardé sur le sud du plateau du Labrador et sur le plateau nord-est, ce qui en a réduit la durée. Dans les autres sous-régions, on a observé des indices de début de floraison uniformes, à l'exception de la sous-région d'Hibernia, où la floraison a débuté tôt et s'est déroulée sur une période prolongée. L'abondance d'*Oithona similis, de Pseudocalanus* sp. et de *Triconia* sp. a atteint (ou presque atteint) des niveaux d'abondance record de la section de la baie Bonavista jusqu'à celle du sud des Grands Bancs. L'abondance de *Calanus glacialis* et de *Calanus hyperboreus* présente un déclin d'abondance à long terme sur le bonnet Flamand et le sud-est des Grands Bancs depuis 2001 et, depuis 2009, sur la section de la baie Bonavista et de l'île des Phoques, à plus court terme. La biomasse des copépodes à la S27 pendant la période 2011-2013, d'après 8 taxons dominants, a connu un déclin contant depuis le pic record de 2009 pour atteindre son niveau le plus bas en 2013. Une analyse des tendances d'abondance saisonnières a permis de constater que des changements marquants dans la phénologie d'espèces écologiquement importantes, tels que *C. finmarchicus* et *Pseudocalanus* sp., se sont produits à la S27 dès 2005, environ, à quel moment la cohorte d'automne a connu une augmentation d'abondance. Les tendances de variations générales parmi les trois niveaux trophiques étudiés dans ce rapport (nutriments, biomasse des phytoplanctons et abondance du zooplancton) ne dévoilent aucune association claire dans les niveaux trophiques, mais l'uniformité de certaines tendances pourrait commencer à donner de nouveaux indices de certains liens trophiques.

INTRODUCTION

The Atlantic Zone Monitoring Program (AZMP) was implemented in 1999 with the aim of increasing Fisheries and Oceans Canada's (DFO) capacity to understand, describe, and forecast the state of the marine ecosystem and to quantify the changes in the ocean physical, chemical and biological properties. A critical element of the AZMP involves an observation program aimed at assessing the variability in nutrients, phytoplankton and zooplankton. The overall aim is to identify fundamental relationships among elements of the planktonic ecosystem and establish how they respond to changes in environmental drivers.

The AZMP derives its information on the state of the marine ecosystem from data collected at a network of sampling locations (fixed point stations, cross-shelf sections, and groundfish surveys) in each region (Quebec, Gulf, Maritimes, Newfoundland) sampled at a frequency of bi-weekly to once annually. The locations of the fixed point station and standard sections for the Newfoundland and Labrador Region are shown in Figure 1.

A description of the seasonal patterns in the distribution of phytoplankton (microscopic plants) and zooplankton (microscopic animals) provides important information about organisms that form the base of the marine foodweb. An understanding of the production cycles of plankton, and their interannual variability, is an essential part of an ecosystem approach to fisheries management.

METHODS

To the extent possible, sample collection and processing conforms to established standard AZMP protocols (Mitchell *et al.* 2002). Non-standard measurements or derived variables are described below.

SAMPLE COLLECTION

Three seasonal oceanographic surveys were conducted in the Newfoundland and Labrador (NL) Region during the 2013 calendar year, in addition to occupations of the high frequency coastal sampling station (S27) during ecosystem trawl surveys (Table 1; Figure 2). We achieved near bi-weekly to monthly occupations of S27 during March-December in 2013; sampling during January-February was not feasible due to lack of suitable vessels.

ANALYSIS

Two simple indices of the vertical physical water-column structure were computed for comparison with optical properties; mixed-layer depth and stratification. The mixed layer depth was determined from observations of the maximum density gradient (gradient$_z$ (sigma-t)). The stratification index (SI) was calculated as:

$$SI\ (kg\ m^{-4}) = (sig\text{-}t_{50} - sig\text{-}t_{z_{min}})/(50 - z_{min})$$

where sig-t_{50} and sig-$t_{z_{min}}$ are interpolated values of sigma-t for the depths of 50 m and z_{min} (the minimum depth of reliable CTD data); typically z_{min} is around 5 m and always less than 9 m.

The availability of light for photosynthesis in an aquatic ecosystem is determined by the penetration of light (Kirk 1994), expressed as the vertical attenuation coefficient (K_d), which is determined by dissolved and coloured substances and particulate matter in seawater. The vertical attenuation coefficient (K_d) was derived from in-water light extinction measurements using a CTD-rosette mounted PAR (photosynthetic active radiation) meter. The downward vertical attenuation coefficient of PAR ($K_{d\text{-}PAR}$) was estimated from the linear regression of

$\ln(E_d(z))$ versus depth z (where $E_d(z)$ is the value of downward PAR irradiance at z m) in the depth interval from near surface to 50 m. When in-water PAR data were not available, the vertical attenuation coefficient was calculated by:

$K_d_chla\ (m^{-1}) = 0.027 m^{-1} + 0.015\ m^{-1} + B(z) * 0.04\ m^{-1}\ (mg\ Chl\ a\ m^{-3})^{-1}$ (Platt *et al.* 1988)

where B(z) is the concentration of chlorophyll *a* in mg m^{-3} (we substitute calibrated chlorophyll *a* from *in-situ* chlorophyll *a* fluorescence when discrete observations were not available) at depth z m. The additional coefficients in this equation are related to the components of pure seawater and dissolved substances. The average value of K_d was calculated for the upper water column using the chlorophyll *a* profile in the upper 50m. The estimate of euphotic depth (ca. depth of 1 % incident PAR) was computed from:

$Z_{eu}\ (m) = 4.6 / K_d$

We substituted K_d_chla when $K_{d\text{-}PAR}$ was not available to compute the euphotic depth.

Annual estimates of water column inventories of nutrients, chlorophyll biomass, the mean abundance of key zooplankton taxa and some physical variables at both the high-frequency sampling site and as an overall average along each of the four standard sections were based on general linear models (GLMs) of the form:

$$Ln(Density) = \alpha + \beta_{YEAR} + \delta_{MONTH} + \varepsilon$$

for S27, where *Density* is in units of m^{-2}, α is the intercept, β and δ are categorical effects for year and month effects, and ε is the error, and

$$Ln(Density) = \alpha + \beta_{YEAR} + \delta_{STATION} + \gamma_{SEASON} + \varepsilon$$

to derive an estimate of the interannual variations based on all occupations of the transects, where δ takes into account the effect of station location and γ takes into account variation among seasons. Density, either in terms of numbers or biomass, was log-transformed to deal with the skewed distribution of the observations. In the case of zooplankton, one was added to the *Density* term to include observations where no animals of a given taxa were counted in the sample. Average integrated physical variables, and inventories of nutrients and chlorophyll were not transformed. An estimate of the least-squares means based on type III sums of squares was used as the measure of the overall year effect.

SATELLITE REMOTE-SENSING OF OCEAN COLOUR

Satellite observations provide a comprehensive spatial and temporal view of surface phytoplankton biomass. We combined Moderate Resolution Imaging Spectrodiometer (MODIS) data obtained continuously from July 2002 until December 2013 with Sea-viewing Wide Field-of-view Sensor (SeaWiFS) from September 1997 until December 2009 to construct composite time series of surface chlorophyll *a* across 11 statistical sub-regions in NL, extending from Hudson Strait down to the Southeast Shoal (see Figure 3 for locations). Basic statistics (mean, range, standard deviation, etc.) are extracted from two week average composites for selected sub-regions. We report on the available time-series of mean surface chlorophyll *a* levels at selected sub-regions on the Newfoundland and Labrador Shelf. Data from both satellite sensors was provided by the Bedford Institute of Oceanography (MODIS and SeaWiFS data) and we computed an average value of surface chlorophyll *a* during the overlap period of the satellites. Data gaps greater than one month in duration were excluded from the analyses.

We used the shifted Gaussian function of time model to describe the characteristics of the seasonal cycle of phytoplankton production based on the combined satellite data

(Zhai *et al.* 2011). Five different metrics were computed using satellite composite data during the spring bloom to characterize bloom dynamics:

(1) background chlorophyll *a* concentration (mg m^{-3});

(2) the integral (magnitude) of chlorophyll *a* concentration under the Gaussian curve (mg m^{-2} d^{-1});

(3) the peak-timing of the spring bloom peak (Julian day);

(4) duration of the spring bloom cycle (days); and

(5) the initiation time of the spring bloom (Julian day). In addition, we computed normalized annual anomalies for each of the different bloom metrics to evaluate evidence of time trends among the different statistical sub-regions.

OBSERVATIONS

PHYSICAL PROPERTIES – FIXED STATION

The seasonal development of various physical indices at S27 has noticeably changed since the start of the monitoring programme was initiated in 1999. The integrated temperature and salinity indices within the upper 50 m have shifted with warm and fresh conditions persisting into mid-February since about 2006, in contrast to early January prior to this time (Figure 4). Enhanced warming and slight freshening is also evident during the winter and spring period in these integrated indices since 2009-10. The seasonal development of temperature appears to be relatively consistent during the late summer and autumn periods but the salinity index has shown a distinct freshening during the autumn that is less prevalent in earlier years (Figure 4). Small shifts in the timing of stratification have also been noted at S27 in recent years. The onset of stratification in the upper water column is slightly earlier along with the breakdown of stratified water during the autumn on the order of a few weeks (Figure 4). Large changes in the evolution of the mixed layer depth have also been observed at S27. The depth of the mixed layer has remained nearly the full extent of the water-column (~ 176 m) throughout April since 2006 compared to approximately 1 month earlier during the early series (Figure 4). Deeper mixed layer depths may act to impede the formation of the spring phytoplankton bloom which depends on maintaining plant cells in the upper water-column where light levels permit rapid growth. Detailed examination of the physical properties at S27 and along the standard Sections can be found in Colbourne *et al.* 2014.

OPTICAL AND BIOLOGICAL PROPERTIES – FIXED STATION

The seasonal development of optical and chlorophyll *a* indices at S27 have shown some reduction in the extent of biological productivity over time. The duration of the spring bloom inferred from the vertical attenuation coefficient, which expresses the extent of light availability due to particulate and dissolved substances within the upper water-column, has gradually declined over the time series indicating a reduction in the standing stocks of phytoplankton (Figure 5). The euphotic depth, which is an inverse function of vertical attenuation, shows an identical temporal trend (Figure 5). An independent measure of particulate matter obtained from *in-situ* chlorophyll *a* fluorescence and discrete pigment inventories within the upper 100 m, shows a nearly identical constriction of the temporal trend over time in standing stocks at S27 during the monitoring programme (Figure 5).

NUTRIENTS AND PHYTOPLANKTON – FIXED STATION AND SECTIONS

The vertical distributions of inorganic nutrients (nitrate, silicate, and phosphate) included in the observational program of the AZMP show strong seasonal co-variation (Petrie *et al.* 1999). For this reason, and because the availabilities of nitrogen and silicate are most often associated with limiting the growth of phytoplankton, more emphasis in this report was placed on variability in these nutrient inventories. The inventories of nutrients are strongly influenced by seasonal biological processes operating throughout the upper water-column. The inventories of nitrate at S27 in the upper 50 m show lower levels several weeks earlier in the spring starting around 2006 and becoming more prominent in recent years (Figure 6). The renewal of nitrate in the upper column that was apparent during the first-half of the time series during the late summer and early autumn is much less pronounced since 2006 (Figure 6). In addition, replenishment of nitrate appears to be delayed in the late autumn in recent years. The deep inventories of nitrate also show evidence of lower levels in recent years during winter-spring (Figure 6). The replenishment of nitrate inventories in the deep strata that typically occurs in the early-late autumn has shown substantial reductions since about 2010. The inventories of silicate also show lower levels in the upper water-column during the spring since 2006 and depletion has started earlier, advancing by ca. 30 days in recent years (Figure 6). The reverse is true for shallow silicate inventories during the summer and early autumn with some replenishment occurring earlier the latter half of the time series. The deep inventories of silicate are relatively consistent throughout the series except for a reduction during the late spring since 2008 (Figure 6).

Both shallow (0-50 m) and deep (50 m-bottom) nutrient inventories show depleted levels at S27 and across Sections in 2013 from 0.5 to 3 standard deviations below normal (Figure 7). The inventories in the deep layer were substantially reduced approaching nearly 3 standard deviation units (~ 40 % reduction in integrated concentrations) below normal compared to the shallow layer. A spatial gradient in the extent of depletion of deep nutrient inventories was also observed with greater negative anomalies along the northern sections and less negative anomalies in the south (Figure 7). The opposite trend was observed in shallow inventories, particularly for silicate levels with higher depletion along the southern sections and declining northwards. Standing stocks of phytoplankton that depend on macronutrients to fuel the spring bloom were mostly below normal in 2013 except for the southeast Grand Bank that showed a marginal positive anomaly (Figure 7). No spatial gradients between the sections and S27 were evident.

Scorecards using normalized, seasonally-adjusted annual anomalies of nutrient availability and phytoplankton biomass along the different sections and S27 were used to assess long-term trends. The phytoplankton inventory inferred from chlorophyll *a* was up slightly in 2013 from record low values observed during 2011-12 (Figure 8). Inventories were depleted by 70-80 % in 2013 along the SI section and S27 compared to the standard climatology. Shallow inventories of silicate and nitrate remain below normal in recent years across S27 and Sections (Figure 8). Shallow inventories are down by 20-50 % in 2013 compared to the standard climatology and most depleted along the southeast Grand Bank section approaching 40-50 %. In addition, deep inventories of these macro-nutrients were well below the annual climatology since 2009-10 (Figure 8). Deep inventories were down by ~ 20-40 % in 2013 compared to the standard climatology and most depleted along the SI section for both silicate and nitrate concentrations. Although the cause for the observed decline in both shallow and deep nutrient inventories in recent years is currently unknown, the lower levels may in part contribute to the reduction in the duration of the spring bloom that was clearly evident at S27 (Figure 5).

To examine trends over the northern and southern areas, we computed composite summed annual anomalies across the Labrador and NE Newfoundland Shelf (northern) and Grand Bank

including Flemish Cap (southern). The composite inventories of macronutrients were relatively coherent across the Labrador and northeast Newfoundland Shelf and Grand Bank (Figure 9). The shallow inventories for both silicate and nitrate revealed shifts between positive and negative anomalies every few years throughout the time series (Figure 9). A clear overall trend is evident in the deep nutrient inventories although, the deep nitrate time series shows more of an abrupt decline after 2008 compared to the silicate time series (Figure 9). Despite the periodic changes and overall negative trends in deep inventories, standing stocks of phytoplankton inferred from chlorophyll *a* biomass remain relatively stable over much of the time series but with slightly reduced levels in composite areas in recent years (Figure 9).

Remote Sensing of Ocean Colour

Satellite ocean colour (MODIS) data provides a large-scale perspective of surface phytoplankton biomass (chlorophyll *a*) over the whole of the NW Atlantic that is not possible for conventional vessel-based sampling. Using two-week satellite composite images of sub-regions off NL supplements our ship-based observations and provides seasonal coverage and a large-scale context with which to interpret our survey data. The ocean colour imagery provides information about the timing and spatial extent of the spring and autumn blooms but does not provide information of the dynamics that take place below the top few meters of the water column. Subsurface information is achieved using the high frequency sampling at S27 and the broad scale oceanographic surveys.

The early development of patchy surface blooms occurred on the south-western areas of the Grand Banks by mid-late March 2013 (composite imagery not shown). The spring bloom intensified rapidly to cover the eastern half of the Grand Bank by late April, with chlorophyll *a* concentrations in excess of 10 mg m^{-3}. By the time of our spring oceanographic survey, in April 2013, chlorophyll *a* concentrations remained high over the central Grand Bank extending out to the Flemish Cap (Figure 2). During the 2013 summer survey, near surface concentrations of chlorophyll *a* were at background levels over much of the northwest Atlantic, with the exception of the southern coastal zone along the Labrador Shelf and Labrador Sea (Figure 2). Extensive cloud cover during the autumn survey in 2013 in late November limited our capacity to detect the areal extent of surface blooms (particularly above the northeast Newfoundland Shelf).

At larger scales, observations from 11 sub-regions off Newfoundland and Labrador indicated that the magnitude of surface phytoplankton blooms detected by MODIS was generally weak in 2013 relative to previous years, particularly from the northern Labrador Shelf down to the Avalon Channel (Figure 10). The only exceptions occurred on the Flemish Pass/Cap and southeast Shoal where surface chlorophyll *a* concentrations was comparable with the long-term trend (Figure 10). In addition, surface blooms occurred somewhat later in the northern sub-regions and across the northeast Shelf while areas on the Flemish Pass/Cap occurred earlier in 2013. The occurrence of autumn blooms, which is sometimes not captured well by conventional sampling, was supported by the high-resolution MODIS imagery across all statistical sub-regions with the exception of the Hudson Strait that exhibits a near continuous production cycle (Figure 10). The satellite data indicate somewhat stronger surface chlorophyll *a* concentrations during the autumn across most sub-regions during the latter part of the time series (Figure 10).

A number of different metrics derived from satellite imagery were examined to characterize the 2013 NL annual anomalies for the extent (background chlorophyll *a*, magnitude and amplitude) and timing (peak timing, duration and initiation) indices of the spring bloom. No evidence of spatial gradients was detected in background chlorophyll *a* levels although, elevated levels were observed in the Hudson Strait and St. Pierre Bank sub-regions (Figure 11). Overall, the

amplitude (peak intensity) and magnitude (integrated chlorophyll *a* biomass) of the spring bloom was below normal across most of the NL sub-regions in 2013 compared to the climatology (1999-2010). Peak timing of the spring bloom was substantially delayed on the northern Labrador and northeast Shelf in contrast to early timing on the Flemish Pass and Cap (Figure 11). The initiation of the spring bloom was delayed on the southern Labrador and northeast Shelf resulting in reduced duration. The other sub-regions showed similar patterns of inter-annual variation in the timing of the spring phytoplankton bloom indices with the exception of Hibernia that initiated substantially earlier resulting in a long duration bloom (Figure 11).

The standardized scorecard anomalies derived from many of the ocean colour metrics showed relatively high spatial and temporal variability across the statistical NL sub-regions during the time series (Figure 12). Relatively stable background chlorophyll *a* levels were noted during 1998 through to 2007 but subsequently changed from 2008 to 2013 with both large positive and negative anomalies. Enhanced background chlorophyll *a* levels have been observed in recent years across the NL statistical sub-regions, with nearly two-thirds of the observations showing positive anomalies since 2010. The largest increase in background levels in 2013 was observed along the Labrador Shelf sections although we were unable to detect the spring bloom cycle on the northern Labrador Shelf. In general, the amplitude and magnitude of the spring bloom has declined in recent years (2011-13) compared to the higher occurrence of positive anomalies that occurred from 2006 to 2010 (Figure 12). The trend in magnitude of the spring bloom was consistently negative across the sub-regions in 2013 with the exception of the southeast shoal of the Grand Bank that showed the only positive anomaly. The largest decline in magnitude was noted on the southern Labrador and northeast Newfoundland Shelf and on the southwest Grand Bank (Figure 12). We also noted some indication in trends toward earlier peak timing, reduced duration, and delayed initiation of the spring bloom from 2006 onward based on the scorecard anomalies across the NL sub-regions (Figure 13). The climatology in timing indicated the peak of the spring bloom typically occurred during April south of the Labrador Shelf but progressively moved to summer months (June-July) northwards. The duration of the bloom was reduced in 2013 across all of the NL sub-regions except for Hibernia where it increased by 60 % of the standard climatology.

To examine for trends over larger areas, we computed composite summed annual anomalies across the Labrador and NE Newfoundland Shelf, Flemish Pass and Cap, and the Grand Bank sub-regions. The composites for background chlorophyll *a* levels remained relatively stable throughout the sub-regions but have increased notably in recent years (2011-12), particularly on the Labrador and NE Shelf and Grand Bank (Figure 14). We observed large shifts from positive to negative composite sums in the magnitude of the spring bloom with the largest amplitude changes occurring on the Labrador and NE Shelf. The composite sums in amplitude of the spring bloom switched from mainly negative values in the first part of the time series to positive in the later part across the sub-regions (Figure 14). A shift from mainly positive to negative anomalies was observed in peak timing and initiation of the spring bloom during 1998 to 2005 indicating a broad-scale response across these areas. Thereafter, the response in the composite timing indices changed between the sub-regions suggesting more localized forcing. The trend in duration of the spring bloom has been in decline since 2006 with ca. 80 % of the composite sums being negative, in contrast to 46 % during 1998-2005. Record-low values in duration of the bloom were also observed on the Labrador and NE Shelf along with the Grand Bank in 2013 and 2012 respectively (Figure 14). The overall trends in the extent of the spring bloom are relatively stable with some substantial positive anomalies observed on the Labrador and NE Shelf and Grand Bank during 2008-11. The timing indices are heavily influenced by trends in peak timing and initiation of the spring bloom with no overall trend apparent (Figure 14).

TRENDS ON OCEANOGRAPHIC SECTIONS – ZOOPLANKTON

Small copepods (Figure 15)-species that contribute to this group can be separated into two categories: those that have shown a general increase in abundance during the period 1999-2013, and those which have declined. Increases have been most notable from the southeast Grand Banks to the Bonavista Bay sections whereas the trends have been more variable on the Seal Island section, probably because of the limited sampling. *Microcalanus* sp., *Oithona atlantica*, *Oithona similis*, *Centropages* sp., and *Spinocalanus* sp. have shown positive trends during the last fourteen years, although *Microcalanus* sp. has declined somewhat on the southeastern Grand Banks section since 2012. *Pseudocalanus* sp. and *Triconia* sp., although abundant in the last few years, have shown considerable variability over time and among sections, with the former being at its lowest level on the Flemish Cap and Bonavista Bay sections in 2011-12 after which it rebounded to reach the highest levels on record in 2013 throughout much of the region. *Chiridius gracilis*, *Acartia* sp. and *Paracalanus parvus* have all been at low levels in recent years, following a long term declining trend. It is noteworthy that there appears to have been an abrupt change in abundance of *Chiridius gracilis* and *Acartia* sp. sometime between 2004 and 2006, with the change being most pronounced on the Bonavista and Seal Island sections (hereafter referenced as the northern ecoregion; Pepin *et al.* 2010) in 2006, possibly reflecting a greater increase in the abundance of taxa that predominate in offshore waters.

Large copepods (Figure 16)-*Calanus finmarchicus* is numerically dominant among the species of large copepods in the region. On the Grand Banks, Flemish Cap and Bonavista Bay sections (hereafter referenced as the southern ecoregion; Pepin *et al.* 2010), abundance of this species has remained high over much of the last decade (including in 2013) relative to levels seen in 1999-2000. Abundance in the northern-most Seal Island section has shown fluctuations, with a peak in 2004-06.

Calanus glacialis is a cold water species that occurs principally over the continental shelf. It is most abundant on the Seal Island section, where the pattern of variation has been relatively similar to that of *C. finmarchicus*, peaking in 2006 after which abundance had declined until a five-fold increase occurred in 2013. Abundance of this species on the Bonavista section has shown very limited inter-annual variability although abundance started to decline in 2010. There has been a persistent decline in the southern ecoregion since the start of the century.

Calanus hyperboreus, the largest of the three *Calanus* species, has shown oscillations in abundance on the southeast Grand Banks section with a general overall decline since 2002. Although variable in abundance on the Flemish Cap section, abundance has declined since 2010. The trend in the northern ecoregion had been toward an increase from 1999 to 2003 after which interannual variations have been limited.

Metridia sp. (which consists of two species *Metridia lucens* and *Metridia longa*) is most abundant in the northern most part of the region. Although there has been no apparent trend on the Seal Island section, there was a general increase in abundance along the Grand Banks, Flemish Cap and Bonavista sections until 2009-10 after which abundance has shown a general decline.

Large calanoid nauplii, which are most abundant on the two northern sections, demonstrate high interannual variations in abundance. The high variability from year-to-year and among sections is likely a reflection of changes in the timing of reproduction by the adults and variable survival rates of the nauplii, which may be dependent on environmental conditions.

Meroplankton (larval stages of *Balanus* sp., bivalves and polychaetes) and other selected taxa (Figure 17) demonstrate a high degree of inter-annual variability in abundance probably

because of variations in the timing of reproduction by the adults and fluctuations in larval survival. There has been a long-term decline in the abundance of *Balanus* sp. on the Grand Banks section since 1999, on the Flemish Cap section since 2010, and on the Seal Island section since 2005, while abundance has remained low on the Bonavista section although there has been a notable and consistent increase in abundance in 2012-2013. Other meroplankton have not exhibited anything more than short-term and localized trends although abundance of polychaetes has been at record levels on the Grand Banks and Flemish Cap sections since 2012. Ostracods have generally shown an increasing trend in the southern ecoregion since the inception of AZMP. The abundance of pelagic gastropods declined substantially in 2011 along the Grand Banks, Flemish Cap and Bonavista sections with some recovery apparent on all three sections in 2013. Abundance on the Seal Island section has remained low since 2006. Larvaceans reached their highest levels of abundance on the Grand Banks and Flemish Cap sections in 2013.

Carnivorous zooplankton (Figure 18) - This group consists of a mixture of taxa that feed predominantly on mesozooplankton. The abundance of the two gelatinous zooplankton species, *Aglantha digitale* and *Pelagia noctiluca*, has generally been decreasing along most oceanographic sections since 2003-06 although the abundance of the latter has remained relatively stable along the Seal Island section. The strength of and variability about the trends vary but the general pattern appears to be consistent. The same pattern has also been apparent for hyperiid amphipods, which have also become less abundant since that time although there is a high degree of variability. In contrast, the abundance of euphausiids (largely juveniles) has generally increased since the inception of the sampling program, although as with other carnivorous zooplankton the strength and variability of the trend differs among species and sections. Abundance of *Euchaeta* sp. and *Sagitta* sp. has been highly variable.

TRENDS – TIME SERIES DATA FROM S27

The high frequency sampling site S27 provides insight into the factors driving seasonal and interannual fluctuations in abundance of key oceanographic variables and zooplankton taxa. Gaps in data collection exceeding 3 weeks are frequent between January and March and between early August and late September, which impacts our ability to infer the significance of variations in population dynamics that may span those intervals. The site is located in inner branch of the Labrador Current and the patterns of variations in the abundance of most chemical and biological variables are likely to reflect principally changes occurring on the inner portion of the Newfoundland Shelf, with variable contributions from offshore areas making inferences that much more complex (Pepin *et al* 2013).

Copepod biomass, based on copepodite and adult stage-dependent abundance and weight of 5 dominant taxa (*Calanus*, *Pseudocalanus*, and *Metridia*) and that of the adults of three genera of small copepods (*Oithona*, *Centropages* and *Temora*), has been in decline from the high levels measured in 2009 and reached the lowest value on record in 2013 (Figure 19). All three species of *Calanus* along with calanoid nauplii, *Metridia* sp., *Oithona* sp., *Pseudocalanus* sp. and *Microcalanus* sp. have essentially been declining in abundance following record abundance levels in 2009 or 2010 (Figure 20). *Triconia* sp., larvaceans and pelagic gastropods reached record or near record high abundance levels in 2013. Many taxa from S27 appear to show a general oscillation over the course of 1999-2013 but there is considerable variability around this cyclic pattern of fluctuation.

COPEPOD PHENOLOGY

Previous reports (e.g. Pepin *et al.* 2011a) have noted a high degree of consistency in the general seasonal succession of stages of *C. finmarchicus* and *Pseudocalanus* sp. during the

last decade. Here we provide a more comprehensive description of the seasonal cycle of abundance of individual stages for the two species. The average (2000-10) seasonal cycle of *C. finmarchicus* at S27 shows evidence of two cohorts of adults. There is a broad peak in abundance of adults (CVI) that starts in January, peaks from mid-March to early-May which then declines until late August after which there is a plateau in the abundance of adults from September until the end of October (Figure 21). In the spring, most adults are females whereas the ratio is closer to 2 females to every 1 male in the autumn. Stage I copepodites (CI) are abundant from late April until mid-September, with a peak from mid-June to mid-August (Figure 21). The occurrence of CII is nearly coincident with that of CIs, largely because development times between stages are generally short. Peak abundance of stage III copepodites (CIII) is delayed until the end of June and the peak in abundance of stage IVs is delayed until early-September, which is much later than if calculated according to Corkett *et al.*'s (1986) estimates of food-saturated temperature-dependent development times based on 0-25 m integrated temperature. Stage V copepodites at S27 have a broad peak in abundance from September until the end of February. In offshore areas, these animals would most likely have entered diapause during this time period. The rise in abundance of CVs is coincident with that of the second peak in adults at S27, consistent with the short development times at high temperatures for copepods not entering diapause (Pepin *t al.*, unpublished data), but the period of high CV abundance persists for longer than that of the adults. This may indicate that CV copepodites are being transported from northern sources over an extended period of time. The second cohort is most strongly represented by the peak in abundance of adults during the autumn and a secondary peak in the abundance of CII–CIV in late December – early January, with a relatively smaller increase in the abundance of CVs in January which could reflect the persistence of the autumn peak in abundance (Figure 21).

Analysis of yearly patterns in abundance reveals that the twin cohorts of adults (CVI) reflects a significant shift in the phenology of *C. finmarchicus* starting approximately in 2005-06, when the fall cohort increases in prominence (Figure 22). This is coincident with high abundances of CV in those years. Starting in 2007, the spring cohort of adults, which has not been preceded by high numbers of CV copepodites, appears to decline in relative abundance and reaches a peak earlier in the year than during the period 1999-2006. These changes in phenology of late stage copepodites are somewhat apparent in the earlier occurrence of C1 copepodite stages in the spring.

The seasonal succession of *Pseudocalanus* sp. has a substantial cohort of CV copepodites from January to March which is closely followed by a peak in the abundance of CVI adults (Figure 23). CI and CII copepodites are abundant from April to August and June to August, respectively. CIII copepodites peak in abundance in June-July and are followed by a broad peak in the abundance of CIVs from August until December. CV copepodites start to increase in abundance in August or September, but it was not until 2005 or 2006 that a second cohort of CVI adults began to appear after late summer periods of high abundance of CVs (Figure 23). The shift in phenology of *Pseudocalanus* sp. is somewhat more dramatic than that of *C. finmarchicus* because the winter cohort of CVs appears to be to prolonged in duration and the summer cohort has an earlier onset starting in 2005-06. There were also indications of an earlier appearance of CIII and CIV copepodites at that time followed by an earlier occurrence of CI copepodites in 2011.

DISCUSSION

There are a number of emerging trends in oceanographic conditions in the region. Data from the high frequency sampling station (S27) indicate that physical habitat indices have gradually shifted in recent years toward warmer winters, greater persistence of a deeper mixed layer

during the spring, and lower salinity in the fall that may affect the occurrence of fall phytoplankton blooms. Warmer winter conditions may affect phytoplankton in two ways by allowing higher background biomass levels to persist through the winter but also by affecting the development of key copepod species. We have noted earlier occurrence of adults and sub-adult copepodites for both *Calanus finmarchicus* and *Pseudocalanus* sp. In the case of the former, preliminary estimates of winter development rates suggest that the slight winter warming may be sufficient to result in the earlier occurrence of adult females (Pepin, unpublished data). Greater persistence of a deep mixed layer in the spring may be affecting the duration of the spring phytoplankton bloom, which has shortened in duration dramatically from 2000 to 2014 (Figure 5), a pattern which is consistent with the broader scale signal identified from remote sensing of surface chlorophyll biomass. These changes are also coupled with some notable trends in the surface and bottom inventories of silicate and nitrate. If these combined trends persist they may have impacts on the regional production potential but we have to be cautious in extrapolating the results on a regional scale because of the high degree of equatorward transport that dominates regional circulation.

At S27, many of the most abundant zooplankton taxa have been showing a decline in abundance over the last 3 to 5 years with a net result that the estimated copepod biomass have reached a record low level in 2013, a pattern that is consistent with overall measured biomass. In contrast, the abundance of some key small (*Oithona similis*, *Pseudocalanus* sp.) copepods appeared to be at or near record levels along the oceanographic sections while the abundance of large copepods has been more variable, with *C. finmarchicus* being generally near or above average while the abundance of two arctic copepods, *Calanus glacialis* and *Calanus hyperboreus*, has been in a decade long decline in the southern ecoregion while the decline has been more recent (2009) on the NL Shelves.

The overall pattern of variation among the three trophic levels surveyed in this report (nutrients, phytoplankton biomass, and zooplankton abundance) does not reveal any clear association among trophic levels but some consistency in some trends may be starting to provide new insights into trophic relationships. Although nutrient inventories across the region are generally at record low levels, the abundance of phytoplankton fluctuates substantially from year-to-year and the general trends in zooplankton abundance indicate that most taxa are near or above their long term (1999-2010) average. However, the pattern of variation of each trophic level demonstrates a high degree of regional coherence, with northern and southern portions of the Newfoundland and Labrador Shelf generally showing similar changes from year-to-year or over longer time scales. This suggests that coherent large-scale processes may be influencing the dynamics of lower trophic levels at the regional level but that identifying the functional relationships with these processes is likely to require careful consideration of the broad variety of influential factors and of the possible complexity of interactions. The high degree of spatial stability in the structure of the NL shelf ecosystem (Pepin *et al.* 2010) and zooplankton community (Pepin *et al.* 2011*b*), may serve to explain the strong regional coherence in the pattern of variation of each lower trophic level. However, the lack of coherence among trophic levels and environmental indices over the short period of observations from our monitoring activities in the region suggests that concepts such as the trophic cascade may not be applicable given the information currently available.

SUMMARY

- Seasonal cycles in temperature and salinity properties at S27 have shifted with warm and fresh conditions persisting well into winter in recent years.

- Changes in vertical mixing inferred from stratification and mixed layer depth indices in recent years at S27 may influence seasonal cycles in macronutrients and standing stocks of phytoplankton.
- Advancing seasonal cycles in physical conditions observed in recent years at S27 appear to result in earlier spring drawdown and delayed recycling of macronutrient levels of silicate and nitrate that has traditionally occurred in the early autumn.
- Seasonally-adjusted annual anomalies of shallow and deep inventories of these macro-nutrients at S27 and across the sections are well below the annual climatology since 2009-10 and in 2013, were approaching 3 standard deviation units below normal.
- In general, inventories of chlorophyll *a* (proxy for phytoplankton standing stock) at S27 and across sections remain below normal in recent years and were at the lowest level observed in the time-series at S27 in 2013.
- Overall, the amplitude (peak intensity) and magnitude (integrated chla biomass) of the spring bloom was below normal across most of the NL sub-regions in 2013 compared to the climatology (1999-2010).
- Timing indices of the spring bloom was substantially delayed on the northern Labrador and northeast Shelf in contrast to the Flemish Pass and Cap that occurred earlier.
- The initiation of the spring bloom was delayed on the southern Labrador and northeast Shelf resulting in reduced duration. The other sub-regions showed consistent timing indices with the exception of Hibernia that initiated substantially earlier resulting in a long duration bloom.
- The overall trends in the extent of the spring bloom are relatively stable with some substantial positive anomalies observed on the Labrador and NE Shelf and Grand Bank during 2008-11.
- No overall trend was detected in the timing indices of the spring bloom across the composite areas due to high interannual variability, particularly in the latter part of the time series.
- The abundance of *Oithona similis*, *Pseudocalanus* sp. and *Triconia* sp. is at or near record levels of abundance from the Bonavista Bay to the southern Grand Banks sections.
- The abundance of *Calanus glacialis* and *Calanus hyperboreus* has shown long-term declines in abundance on the Flemish Cap and southeast Grand Bank starting in 2001, and shorter term declines on the Bonavista Bay and Seal Island section since 2009.
- Copepodite biomass at S27 in 2011-13, based on the abundance of 8 dominant taxa, has demonstrated a consistent decline over time to a record low value in 2013 since the record high levels observed in 2009.
- Analysis of yearly patterns in abundance reveals dramatic shifts in phenology of ecologically-important copepod species such as *C. finmarchicus* and *Pseudocalanus* sp. have occurred at S27 starting approximately in 2005, when the fall cohorts increases in relative abundance.

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APPENDIX 1

*Table 1. AZMP sampling missions in Newfoundland and Labrador Region in 2013.**

Group	Location	Mission ID	Dates	# Hydro Stations	# Net Stations
Ecosystem Trawl Surveys	NE Newfoundland Shelf and Grand Bank	NED2013-430-435	Mar 25-Jun 21	508	6
Ecosystem Trawl Surveys	Grand Bank, NE Newfoundland and Labrador Shelves	NED2013-438-443, TEL-2013-119-124	Sep 18-Dec 11	690	7
Seasonal Sections	Grand Bank and NE Newfoundland Shelf	TEL2013-114	Apr 10-29	157	73
Seasonal Sections	Grand Bank, Newfoundland and Labrador Shelves	TEL2013-117	Jul 9-28	109	64
Seasonal Sections	Grand Bank and NE Newfoundland Shelf	HUD2013-113	Nov 20-Dec 9	114	74
Fixed Station	Station 27	Ships of Opportunity	Mar-Dec	39	27
Total	-	-	-	**1617**	**251**

* Numbers of net stations refer to dedicated plankton net occupations at Station 27 during Ecosystem Trawl Surveys.

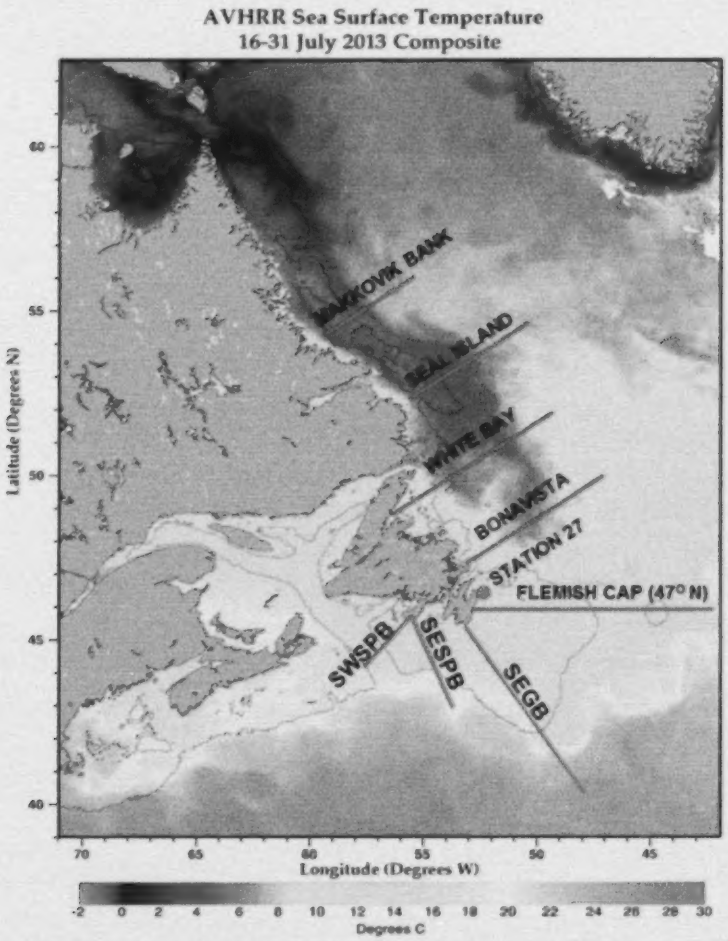

Figure 1. Map showing Station 27 and standard oceanographic sections sampled during 2013 (2013 SST map courtesy of the Ocean Research and Monitoring Section, BIO).

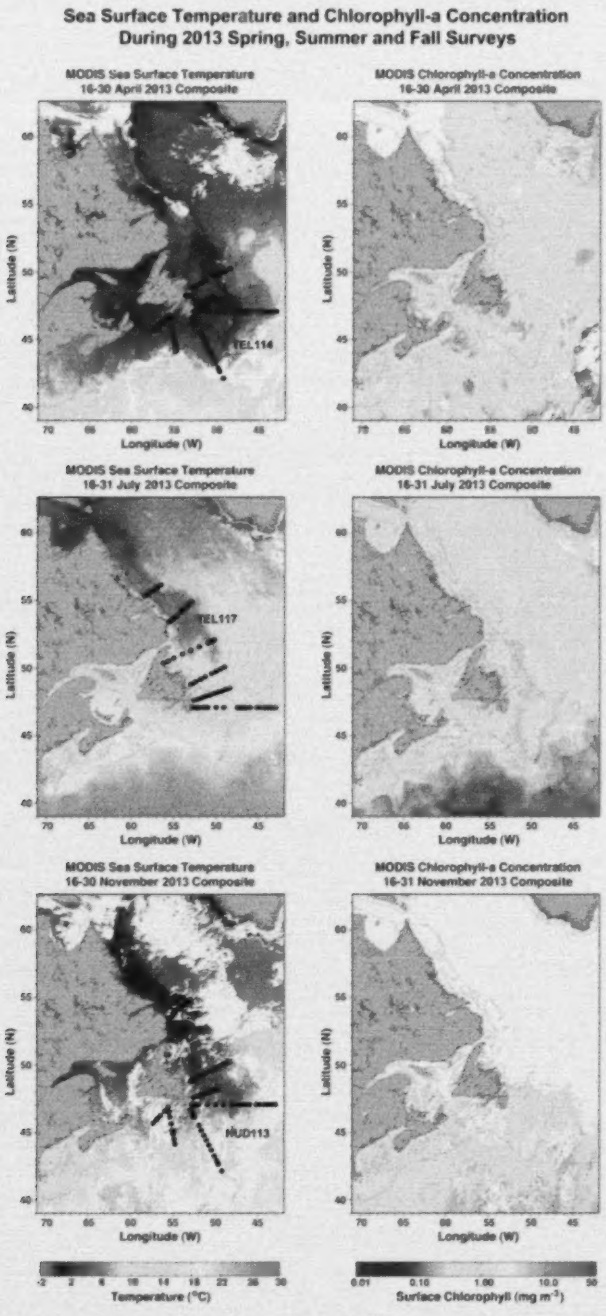

Figure 2. Station occupations during the 2013 (left panels) spring (TEL114), summer (TEL117), and fall (HUD113) section surveys, respectively. Station locations superimposed on twice-monthly sea-surface temperature composite images (left-side panels). Corresponding ocean colour composite images provided (right-side panels) for each sampling season.

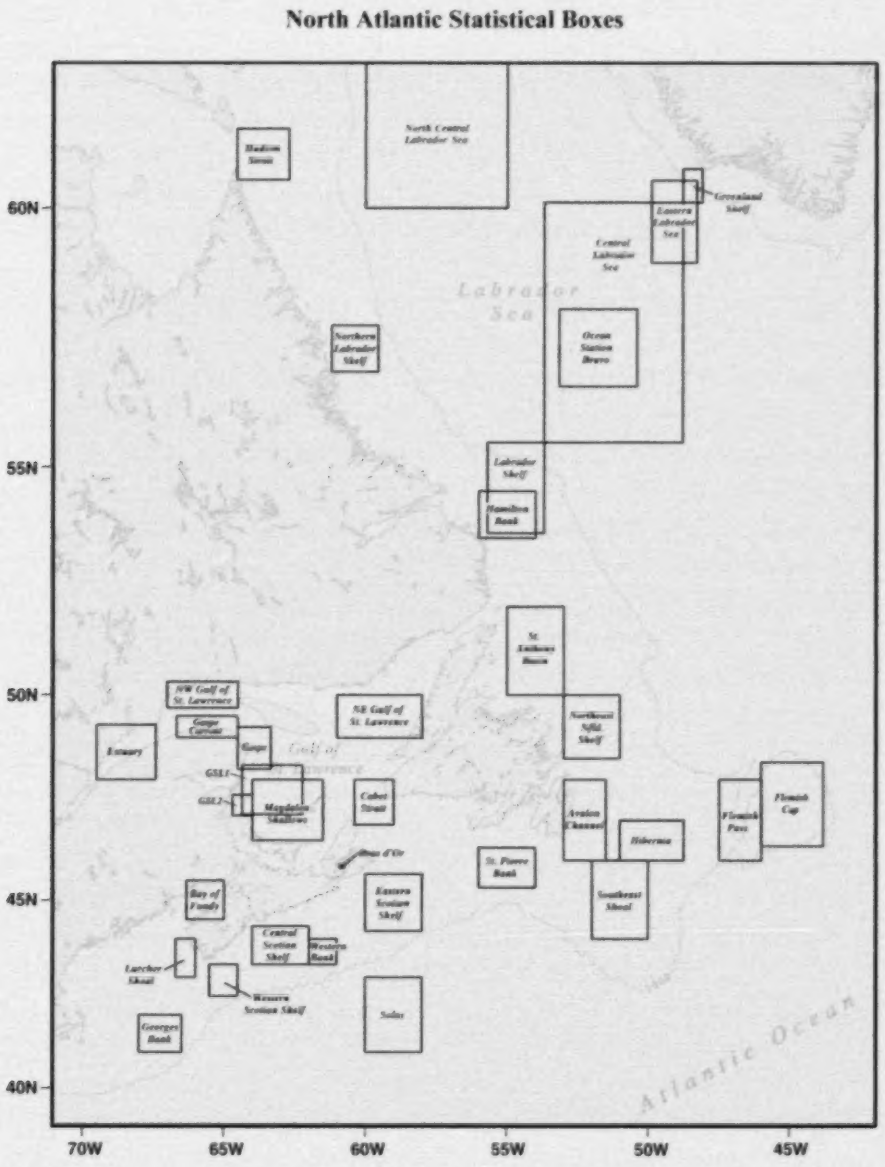

Figure 3. Statistical sub-regions in the Northwest Atlantic identified for spatial/temporal analysis of satellite ocean colour data. Sub-regions in the Newfoundland and Labrador Region include St. Pierre Bank, southeast Shoal, Avalon Channel, Hibernia, Flemish Pass and Flemish Cap, northeast Newfoundland Shelf, St. Anthony Basin, Hamilton Bank, northern Labrador Shelf, and Hudson Strait. Sub-regions examined across the Labrador Sea include the Labrador Shelf, Ocean Station Bravo, central Labrador Sea and Greenland Shelf.

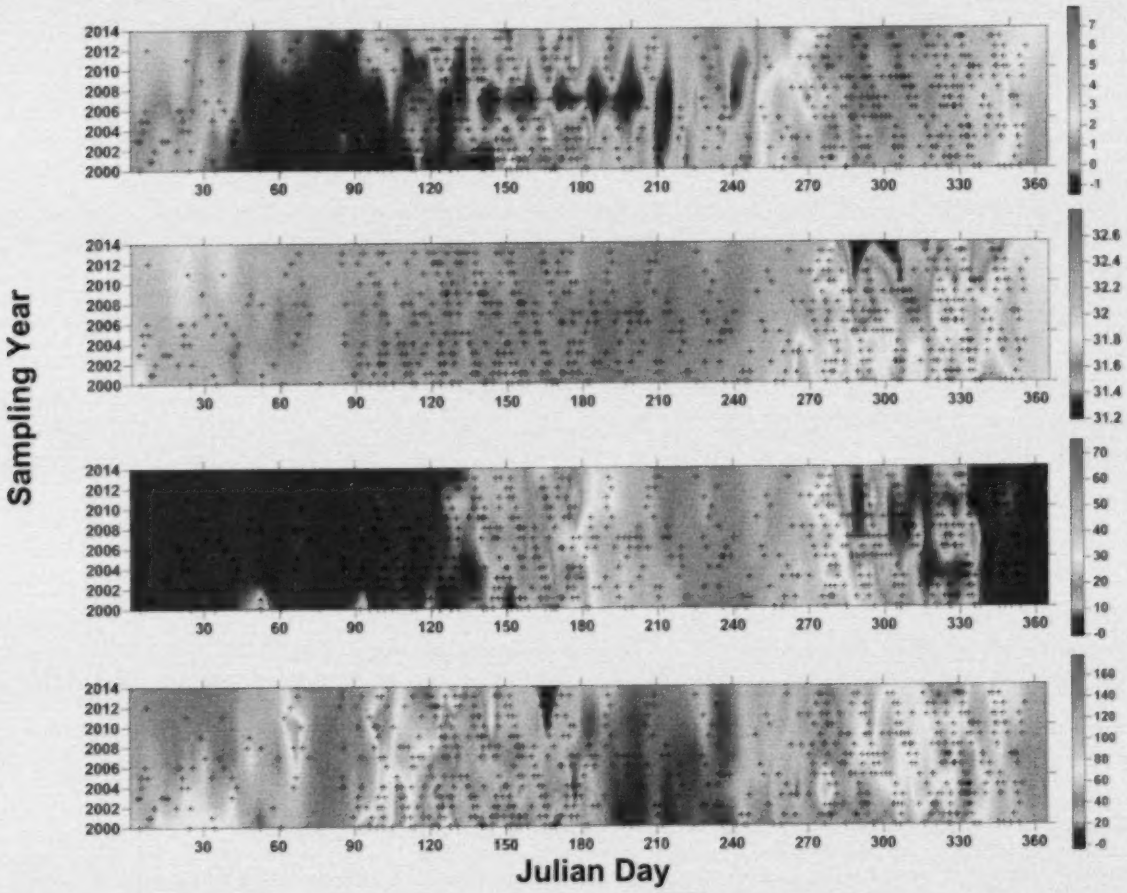

Figure 4. Physical habitat seasonal indices at S27 during 2000 to 2013. Average thermal (°C) and salinity (psu) indices within the upper 50m (top panels respectively). Stratification (Kg m^{-4}) and mixed layer depth (m) indices (lower panels respectively). Plus symbols in contour maps indicate timing of respective measurements for different physical indices.

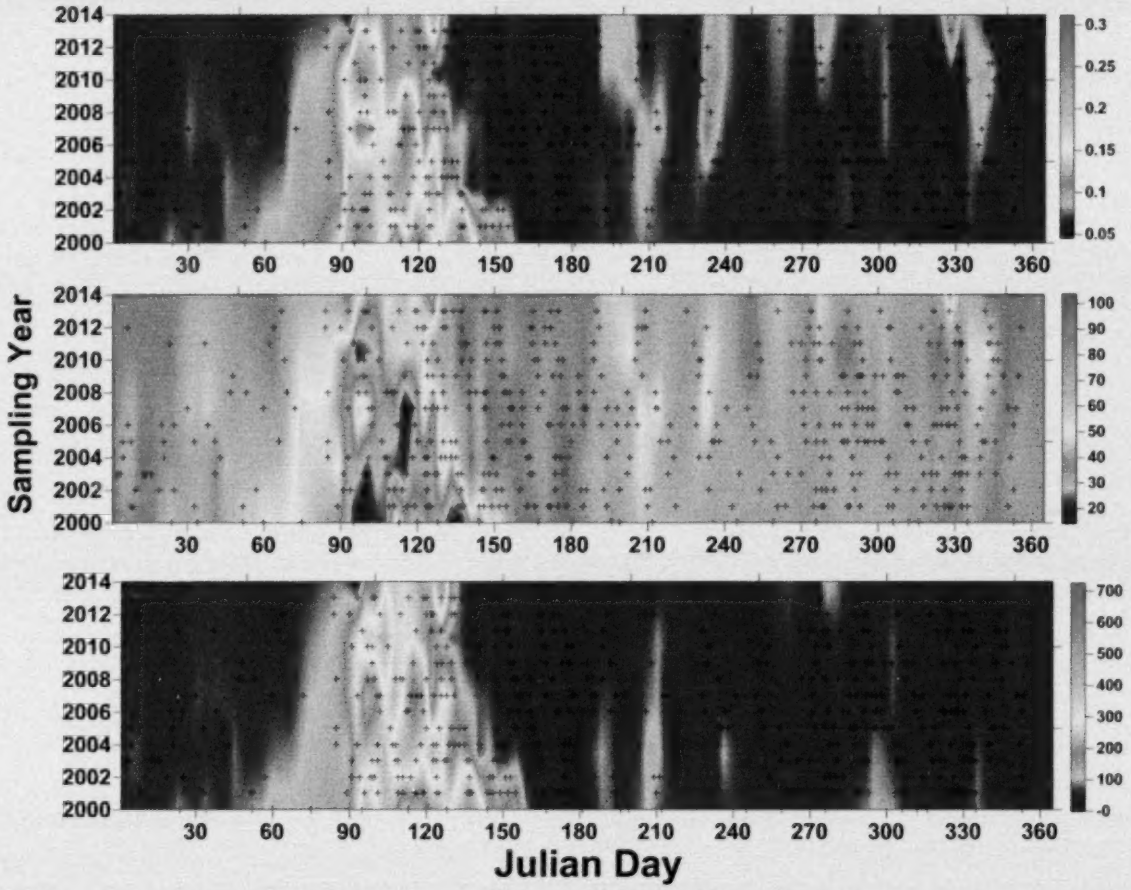

Figure 5. Optical and chlorophyll a pigment properties determined from in-situ PAR (photosynthetic active radiation) and combination of discrete extracted and fluorometric chlorophyll a profiling at Station 27 during 2000 to 2013. Vertical attenuation coefficient in m^{-1} (top panel) determined in the upper 50 m of the water column, euphotic depth (depth in m of the 1 % PAR level; middle panel), and integrated chlorophyll a (mg m^{-2}) within the upper 100 m of the water column. Plus symbols in contour maps indicate timing of respective measurements for different optical and biological indices.

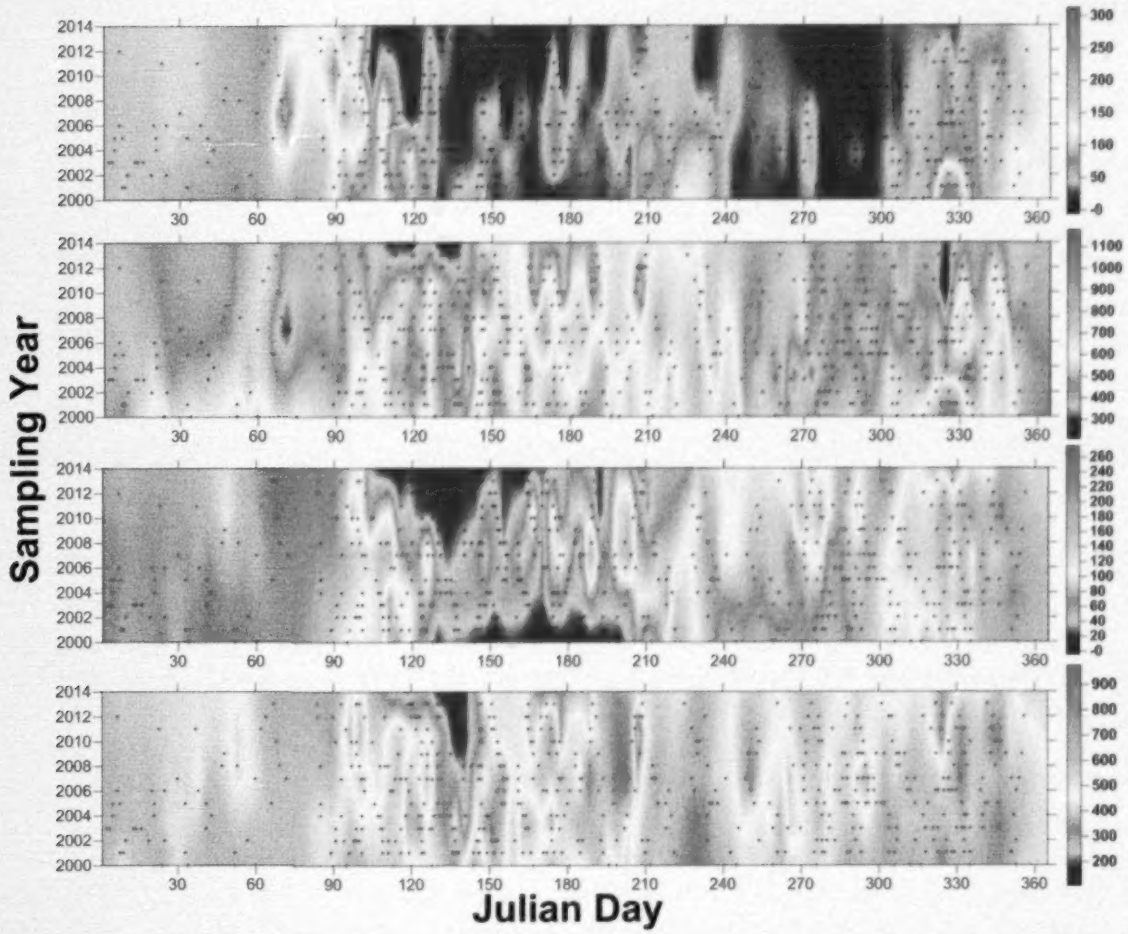

Figure 6. Shallow and deep nutrient inventories at S27 during 2000 to 2013. Shallow (upper 50m) and deep (50-150m) inventories (mmol m^{-2}) of nitrate (upper two panels respectively) along with corresponding inventories of silicate (lower two panels respectively). Plus symbols in contour maps indicate timing of respective measurements for the nutrient inventories at S27.

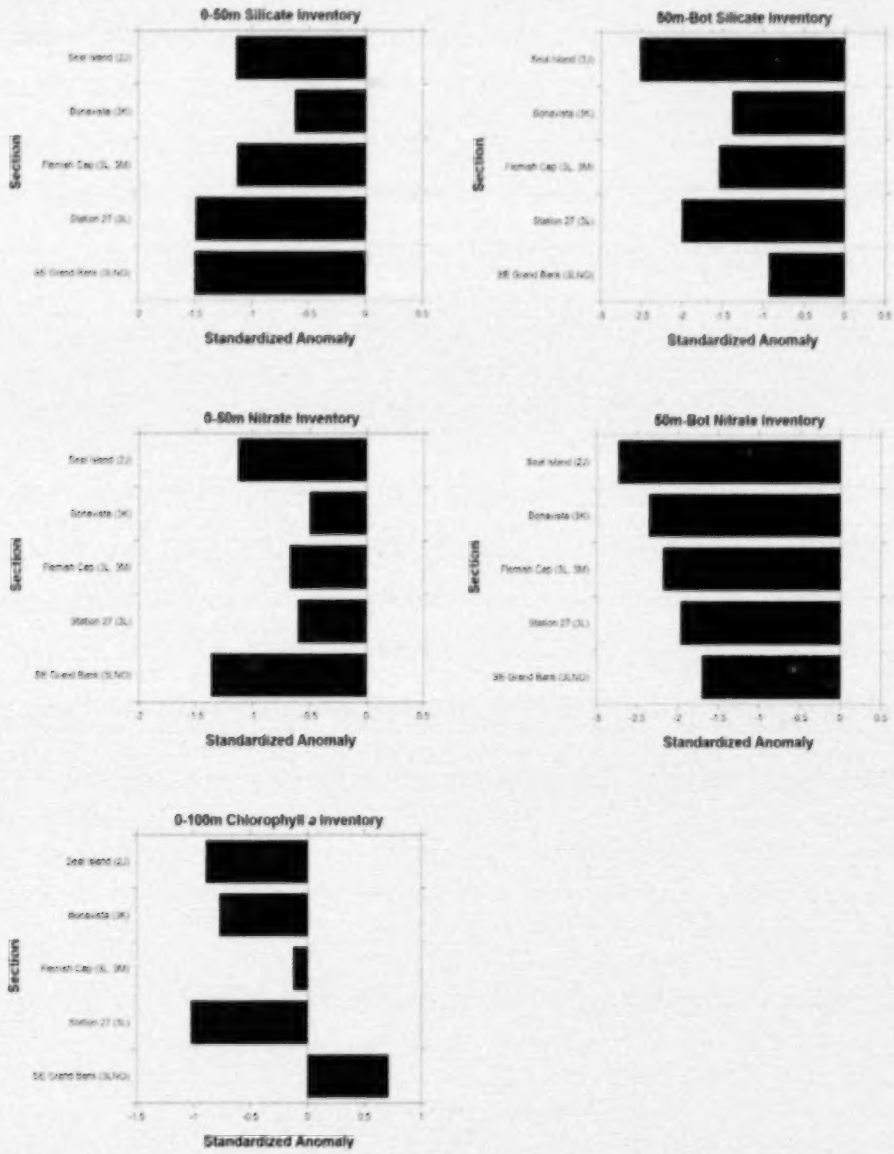

Figure 7. Summary of annual anomalies of chlorophyll and nutrient inventories from the Sections and Fixed Station (S27) during 2013. The upper panels show the shallow and deep silicate inventories; middle panels show the corresponding nitrate inventories; bottom left panel shows the water-column integrated chlorophyll a inventory. The standardized anomalies are the differences between the annual average for 2013 and the long-term mean (1999-2010) divided by the standard deviation. The Sections and fixed station (S27) are sorted from northern (top) to southern (bottom). Negative anomalies imply below average levels while positive values indicate the reverse.

Chla 0_100m

Location	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Mean ± S.D.	% Difference
Seal Island (2J)	2.78	0.12	0.75	0.13	0.76	0.43	0.11	0.12	0.90	0.07	0.06	0.75	1.08	0.95	0.86	75.1 ± 91.1	-72.0
Bonavista (3K)	1.35	1.15	0.13	1.22	1.53	0.95	0.62	0.57	0.34	0.91	1.34	0.18	1.25	1.69	0.77	91.1 ± 37.7	-31.9
Flemish Cap (3L, 3M)	2.19	0.20	0.18	0.91	1.75	0.06	0.16	0.67	0.93	0.49	1.02	0.08	1.95	1.48	0.13	122.4 ± 22.1	-2.2
Station 27 (3L)	2.55	0.13	0.02	0.09	0.49	0.73	0.55	0.73	0.54	0.75	0.14	0.77	0.72	0.35	1.07	184.9 ± 84.7	-82.3
SE Grand Bank (3LNO)	2.08	1.35	0.79	0.36	1.02	0.39	0.57	0.58	0.75	1.07	1.07	0.21	1.86	0.08	0.79	113.7 ± 38.5	24.7
Silicate 0_50m	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**		
Seal Island (2J)	0.79	0.39	1.65	0.72		0.47	0.73	1.79	0.96	0.13	0.35	1.84	0.58	0.74	1.14	186.9 ± 52.8	-32.3
Bonavista (3K)	0.95	0.49	0.42	1.71	1.90	0.03	1.05	1.09	0.44	0.65	1.29	0.86	0.15	1.60	0.62	186.1 ± 53.3	-18.9
Flemish Cap (3L, 3M)	0.66	1.30	0.32	0.98	1.57	0.64	0.04	0.13	0.91	0.33	1.26	1.44	1.68	1.94	1.13	114.8 ± 28.4	-27.9
Station 27 (3L)		1.73	1.07	1.17	0.91	0.33	0.50	0.39	0.69	0.37	0.71	1.84	0.95	0.39	1.46	124.9 ± 21.5	-25.7
SE Grand Bank (3LNO)	1.38	1.58	0.78	0.52	1.28	0.89	0.24	0.63	1.22	0.62	0.73	0.80	1.94	0.11	1.58	113.0 ± 38.5	-40.5
Silicate 50_Bot	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**		
Seal Island (2J)	1.01	1.07	0.37	0.61		0.14	0.76	1.37	1.55	1.05	1.17	0.71	1.76	2.23	2.06	752.2 ± 118.6	-38.0
Bonavista (3K)	2.37	0.19	0.21	0.95	0.12	0.11	0.47	1.29	0.16	0.67	1.05	0.97	1.65	1.66	1.39	763.6 ± 99.0	-17.9
Flemish Cap (3L, 3M)	2.28	0.47	0.15	0.15	0.22	0.36	0.39	0.90	0.39	1.04	1.10	1.40	0.61	1.97	1.54	570.3 ± 78.9	-20.7
Station 27 (3L)		0.65	0.95	1.91	0.52	0.57	0.15	1.67	0.04	0.63	1.23	1.66	0.79	2.36	2.08	560.1 ± 86.9	-23.6
SE Grand Bank (3LNO)	2.37	0.47	0.18	0.76	0.09	0.69	0.01	0.63	0.35	0.05	1.75	0.76	0.56	0.31	0.95	383.3 ± 77.5	-18.9
Nitrate 0_50m	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**		
Seal Island (2J)	1.06	0.64	0.25	0.24		1.48	0.05	1.86	0.44	0.46	0.14	1.37	1.02	0.74	1.13	185.8 ± 38.1	-34.7
Bonavista (3K)	0.04	0.13	0.35	1.58	1.58	0.28	0.81	1.35	1.08	0.36	0.20	1.28	0.16	0.44	0.56	209.8 ± 55.1	-13.1
Flemish Cap (3L, 3M)	0.06	0.84	0.27	1.15	2.07	0.61	0.41	0.49	0.58	0.74	0.63	1.58	1.55	0.76	0.67	119.6 ± 45.0	-25.1
Station 27 (3L)		0.09	1.78	0.48	0.06	0.65	0.15	0.86	0.05	0.16	0.61	2.08	0.55	1.18	0.06	82.9 ± 16.4	-11.8
SE Grand Bank (3LNO)	0.05	0.45	0.06	0.25	2.48	0.72	0.22	0.95	0.25	0.54	0.46	1.62	0.82	0.20	1.28	84.0 ± 38.4	-48.3
Nitrate 50_Bot	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**		
Seal Island (2J)	0.01	0.49	0.96	0.41		0.82	0.50	0.41	1.28	2.08	0.80	1.40	0.70	1.64	2.31	824.5 ± 108.1	-35.8
Bonavista (3K)	0.79	0.83	1.31	0.05	0.82	0.73	0.12	0.70	0.55	0.40	0.56	2.26	1.20	1.11	2.35	955.8 ± 75.1	-18.4
Flemish Cap (3L, 3M)	0.87	0.57	0.46	1.10	0.75	0.09	0.59	1.46	0.70	0.30	1.14	1.91	0.18	2.36	2.18	773.3 ± 91.9	-17.5
Station 27 (3L)		1.25	0.27	0.20	0.79	0.56	0.03	0.16	0.92	1.46	0.83	1.87	1.03	0.95	1.95	533.8 ± 68.0	-22.1
SE Grand Bank (3LNO)	1.96	0.44	0.24	0.68	0.36	0.66	0.13	0.49	0.06	0.19	2.28	1.10	0.36	0.34	1.75	453.7 ± 98.3	-22.7

Figure 8. Annual scorecard anomalies of shallow (0-50 m) and deep (50m-bottom) nutrient (silicate and nitrate) and chlorophyll a (0-100 m) inventories across the different ocean sections and fixed station (Station 27). The reference period used to compute annual anomalies was 1999 to 2010. The numbers on the right of the standardized anomalies are the 1999–2010 climatological means and standard deviations (Chlorophyll a units are mg Chla m^{-2} and for shallow and deep nutrient inventories units are mmol m^{-2}) and the percent difference between the 2013 annual mean and the climatology mean. The numbers in the boxes are normalized anomalies. Nutrient data was not available for the Seal Island Section in 2003.

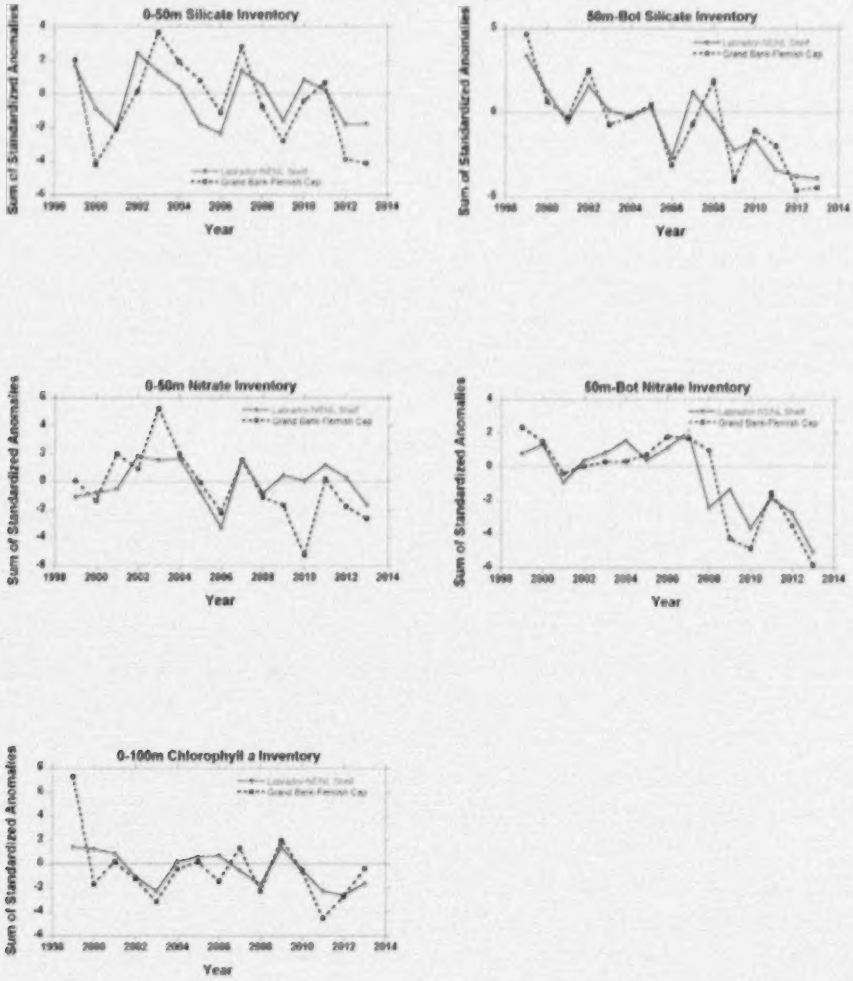

Figure 9. Composite annual anomalies in chlorophyll a and nutrient inventories across the Labrador and northeast Newfoundland Shelf (LAB-NENL Shelf); and Grand Bank – Flemish Pass/Cap Sections and fixed station (S27). The upper panels show the shallow and deep silicate inventories; middle panels show the corresponding nitrate inventories; bottom left panel shows the water-column integrated chlorophyll a inventory. The summed standardized anomalies are the differences between the annual average for a given year and the long-term mean (1999-2010) divided by the standard deviation. Negative anomalies imply below average levels while positive values indicate the reverse.

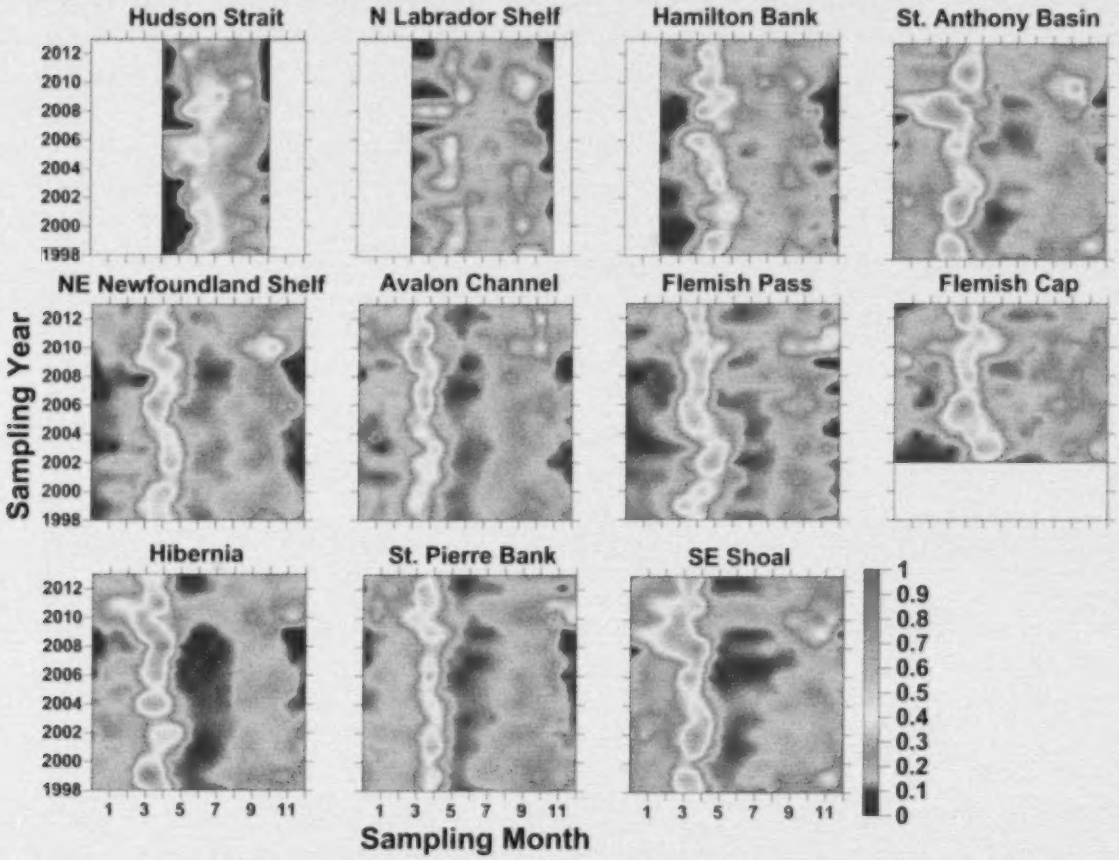

Figure 10. Time-series of surface chlorophyll a concentrations (log-transformed + 1; mg m^{-3}), from combined SeaWiFS and MODIS ocean colour data along statistical sub-regions across the Newfoundland and Labrador area during 1998-2013. SeaWifs data for the Flemish Cap was not available prior to July 2002. See Figure 1 for locations of statistical sub-regions in Newfoundland and Labrador area. Normal ice-covered periods and unavailable data are blocked out in white.

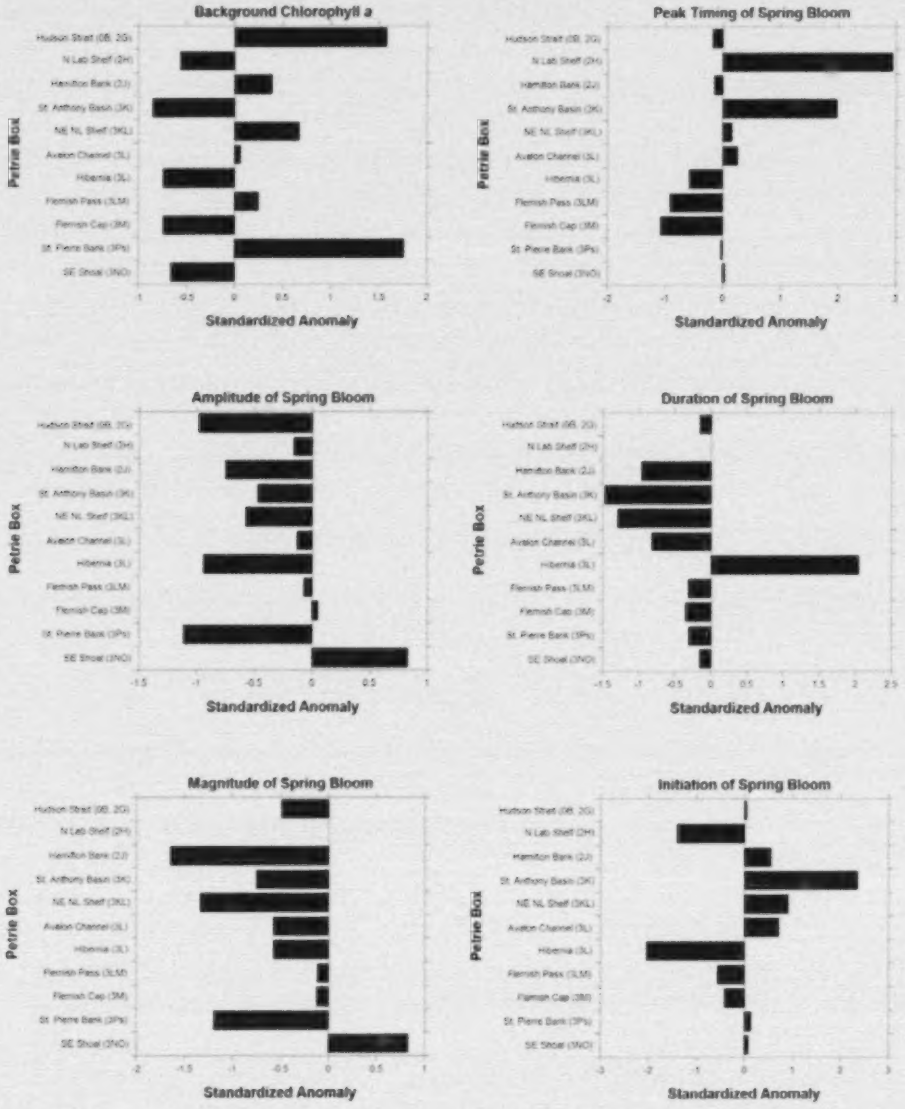

Figure 11. Summary of annual ocean colour anomalies from Moderate Resolution Imaging Spectroradiometer (MODIS) "Aqua" sensor imagery across the different statistical sub-regions during 2013. The left panels show the extent of the spring production cycle while the right panels indicate the different timing indices. The standardized anomalies are the differences between the annual average for a given year and the long-term mean (1998-2010) divided by the standard deviation. The statistical sub-regions are sorted from northern (top) to southern (bottom) boxes. Negative anomalies for the timing indices (peak timing, duration and initiation) indicate earlier/shorter blooms while positive anomalies indicate the reverse.

Background Chlorophyll a																		
Location	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Mean ± SD	% Difference in 2013
Hudson Strait (0B, 2G)	-0.81	-0.49	-0.37	-0.62	-0.10	0.53	1.78	-0.25	-1.98	0.16	-0.90	1.72	0.90	0.07	-0.66	1.58	0.11 ± 0.03	298.7
N Labrador Shelf (2H)	-0.67	-0.38	-0.66	0.41	0.07	-0.78	1.12	-0.71	0.73	-0.03	0.04	-1.91	2.37	5.70	-1.38		0.22 ± 0.07	
Hamilton Bank (2J)	0.69	-1.37	-0.77	0.49	-0.78	0.01	1.86	-0.36	0.08	-0.75	-0.74	-0.31	1.87	2.47	-0.08	0.39	0.24 ± 0.17	49.1
St. Anthony Basin (3K)	-0.33	-0.27	-0.23	-0.07	0.72	0.51	-0.56	-0.31	-0.47	-0.33	-1.31	2.91	-0.27	0.53	-1.29	-0.88	0.70 ± 0.32	-11.8
NE Newfoundland Shelf (3KL)	0.61	-1.82	0.45	-0.24	0.96	-1.18	0.20	-0.32	-0.33	-0.17	-1.48	-0.09	2.44	2.61	0.84	0.67	0.36 ± 0.11	-16.0
Avalon Channel (3L)	0.04	-0.01	-0.28	-1.68	-0.08	-0.65	-0.73	-0.78	0.08	0.49	0.03	-0.06	3.80	4.29	1.09	0.06	0.42 ± 0.14	-64.3
Hibernia (3L)	0.06	-0.31	-0.31	-0.35	0.67	0.97	-0.86	-0.48	0.29	-0.25	-1.22	-0.87	2.63	4.24	-0.09	-0.74	0.52 ± 0.18	-25.6
Flemish Pass (3L, 3M)	-0.09	0.46	0.75	-0.44	1.03	-1.14	-0.38	0.48	-0.56	-0.15	-1.45	-0.18	2.26	0.62	1.18	0.25	0.33 ± 0.10	32.3
Flemish Cap (3M)						-1.38	-0.34	0.31	-0.31	-0.04	-0.18	-0.21	2.18	0.69	1.88	-0.74	0.39 ± 0.15	-55.4
St. Pierre Bank (3Ps)	0.12	1.95	-0.17	-0.61	1.78	-0.16	-0.72	-0.42	0.75	-0.46	-0.58	-1.81	0.19	5.61	3.80	1.76	0.47 ± 0.08	34.9
SE Shoal (3NO)	-0.81	-0.73	-0.68	-0.56	0.52	0.69	-0.53	-0.61	-0.59	-0.63	1.54	2.36	-0.03	0.43	-0.10	-0.66	0.81 ± 0.27	-47.7
Magnitude of Spring Bloom																		
Location	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013		
Hudson Strait (0B, 2G)	0.21	-0.71	-0.34	-0.78	-0.46	2.98	-0.41	0.12	0.82	-0.52	-0.43	-0.57	0.09	-0.76	-0.59	-0.49	60.3 ± 87.0	-26.5
N Labrador Shelf (2H)	-0.01	-0.02	-0.65	0.61	-1.88	0.72	-0.69	-0.15	-0.08	-0.47	2.79	0.01	-1.88	-0.75	-0.66		41.1 ± 22.9	
Hamilton Bank (2J)	-0.38	0.72	-1.14	1.54	-0.96	-0.54	-1.68	-0.22	0.91	-1.44	0.51	0.97	1.08	-0.93	-0.07	-1.84	68.2 ± 24.8	-59.5
St. Anthony Basin (3K)	-0.25	0.27	-0.93	-0.05	0.72	-0.34	-0.50	-0.75	-0.26	-0.65	2.96	0.26	-0.47	0.72	-0.51	-0.75	91.2 ± 76.4	-62.7
NE Newfoundland Shelf (3KL)	0.05	0.20	0.57	-1.38	0.08	-0.55	-0.72	-0.82	1.57	-0.24	-0.70	2.27	-0.35	3.06	-0.93	-1.38	79.4 ± 37.7	-63.3
Avalon Channel (3L)	1.46	-0.74	-0.68	-0.16	0.37	-0.33	-0.38	-0.76	0.22	0.42	-0.19	1.32	2.41	0.81	-0.85	-0.57	62.1 ± 25.3	-23.4
Hibernia (3L)	-0.63	1.68	1.68	-0.96	-0.25	-1.33	0.63	-1.12	-0.29	-0.28	1.02	0.33	-0.50	-0.14	-0.96	-0.57	123.1 ± 76.4	-35.4
Flemish Pass (3L, 3M)	-1.46	-0.36	-0.02	-1.28	1.83	-0.31	0.28	0.58	-0.28	-0.22	-1.14	1.47	0.88	-1.68	-0.78	-0.11	83.8 ± 24.1	-3.1
Flemish Cap (3M)						0.59	0.10	0.82	1.19	-1.84	-0.73	-0.97	0.65	-1.00	-0.22	-0.12	106 ± 47.6	-5.6
St. Pierre Bank (3Ps)	-0.83	-0.40	-1.12	1.73	-0.24	-0.68	-0.01	-0.46	0.14	-0.23	-1.03	1.81	1.33	0.52	1.44	-1.19	50.8 ± 21.0	-49.2
SE Shoal (3NO)	-0.38	0.53	-1.81	-0.02	1.34	-0.45	-0.85	-1.82	0.24	-0.85	1.39	0.96	0.17	0.48	-0.90	0.83	88.5 ± 43.7	40.8
Amplitude of Spring Bloom																		
Location	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013		
Hudson Strait (0B, 2G)	-0.70	0.44	-0.35	0.84	-0.86	1.04	-1.27	-0.06	-0.23	-1.27	1.41	1.71	-0.67	1.94	-1.49	-0.96	1.5 ± 0.4	-23.6
N Labrador Shelf (2H)	-0.42	0.09	-0.21	-0.51	-0.77	-0.02	-0.49	0.99	-0.19	-0.72	0.06	2.93	-0.74	-0.09	-0.58		1.2 ± 0.7	
Hamilton Bank (2J)	-0.78	1.34	-0.95	-0.51	-0.94	0.27	-0.89	-0.63	0.46	-0.74	2.14	0.12	1.03	-0.29	0.08	-0.75	2.1 ± 1.2	-44.6
St. Anthony Basin (3K)	-0.55	0.55	-1.15	0.83	1.63	-0.40	-0.78	-1.15	-0.28	-0.41	1.63	0.64	-0.93	2.26	-0.83	-0.47	2.6 ± 1.5	-27.7
NE Newfoundland Shelf (3KL)	-0.56	-0.66	0.00	-1.17	0.42	-0.46	-0.73	-0.37	1.86	2.15	-0.82	0.01	0.34	3.95	-0.73	-0.57	2.7 ± 1.4	-31.0
Avalon Channel (3L)	-0.96	-0.63	-0.48	-0.70	-0.56	-0.14	-0.65	-0.92	0.56	0.93	0.03	1.03	2.49	1.12	0.35	-0.13	2.5 ± 1.7	-8.9
Hibernia (3L)	-0.74	1.39	1.39	-0.98	-0.77	-1.28	-0.06	-1.06	0.09	-0.03	1.62	0.19	0.01	0.68	-0.76	-0.94	4.3 ± 2.9	-63.3
Flemish Pass (3L, 3M)	-0.87	-0.06	-0.36	-1.48	2.04	-0.30	-1.91	0.87	-0.04	1.23	0.28	0.66	-1.85	-0.01	1.64	-0.07	2.3 ± 1.1	-3.1
Flemish Cap (3M)						0.36	-0.63	-0.36	2.07	-1.68	0.62	-0.29	-0.76	0.11	2.16	0.95	2.6 ± 1.4	3.1
St. Pierre Bank (3Ps)	-0.42	0.39	-0.96	2.88	-0.69	-0.33	-0.26	0.99	1.51	-0.24	-1.45	-0.07	-0.57	-0.14	4.89	-1.11	2.1 ± 0.9	-46.3
SE Shoal (3NO)	-0.96	0.06	-1.58	0.32	1.24	0.10	-0.93	-1.26	0.46	-0.27	1.93	-0.08	0.86	-1.29	-0.42	0.83	3.3 ± 1.6	41.4

Figure 12. Annual standardized scorecard anomaly indices for background Chlorophyll a, overall magnitude (integrated chlorophyll a concentration), and amplitude (intensity) of the spring bloom across the Newfoundland and Labrador statistical sub-regions during 1998-2013. Data for Flemish Cap not available during 1998-2002. The standardized anomalies are the differences between the annual average for a given year and the long-term mean (1998-2010) divided by the standard deviation. The numbers on the right of the standardized anomalies are the 1998–2010 climatological means and standard deviations for the different ocean colour metrics; background chlorophyll a in mg m^{-3}, magnitude of the spring bloom in mg m^{-2}, and amplitude of the spring bloom in mg m^{-3} and the percent difference between the 2013 annual mean and the climatology mean. The numbers in the boxes are normalized anomalies. The statistical sub-regions are sorted from northern (top) to southern (bottom) boxes. Blank cells indicate the fitting routine could not be achieved. Data for Flemish Cap are not yet available during 1998-2002.

Peak Timing of Spring Bloom

Location	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Mean ± SD	% Difference in 2013
Hudson Strait (0B, 2G)	0.43	-0.33	0.59	-0.70	-0.14	2.43	-0.71	-1.16	-0.74	0.88	-1.19	0.14	0.52	-0.11	-0.46	-0.17	208.8 ± 21.2	-1.8
N Labrador Shelf (2H)	-0.41	-0.10	0.13	-0.42	0.78	-0.66	-0.26	-0.41	-0.44	2.86	-1.41	0.27	0.09	-0.40	-0.24		168.9 ± 35.4	
Hamilton Bank (2J)	-0.55	-0.18	1.15	0.84	1.56	0.25	-0.12	-0.51	-1.80	0.83	-1.19	0.72	-1.00	-0.26	-0.86	-0.14	151.2 ± 15.6	-1.5
St. Anthony Basin (3K)	-0.20	-0.70	-1.03	0.09	0.25	1.84	0.81	0.13	-0.08	0.37	-1.11	-1.74	1.37	1.12	1.48	1.98	107.7 ± 15.5	28.4
NE Newfoundland Shelf (3KL)	-0.34	-1.17	0.17	1.48	1.32	1.19	0.67	-0.85	-1.05	0.02	0.60	-0.33	-1.63	0.02	-0.67	0.16	120.3 ± 10.9	1.5
Avalon Channel (3L)	0.00	-1.21	-0.54	1.09	0.42	2.12	-0.18	-0.93	0.32	0.03	1.01	-0.87	-1.26	0.14	-0.66	0.25	109.0 ± 9.6	2.2
Hibernia (3L)	0.69	-0.90	-0.90	0.85	1.72	0.40	-0.32	0.20	0.09	0.12	0.91	-0.76	-2.12	0.31	-0.47	-0.58	107.4 ± 11.3	-6.1
Flemish Pass (3L, 3M)	-0.31	-1.72	0.19	1.14	1.19	1.81	0.18	-0.80	-1.37	-0.22	-0.24	-0.34	0.58	-0.13	-0.63	-0.91	126.3 ± 15.5	-11.2
Flemish Cap (3M)						1.98	0.76	-0.86	-0.81	-0.50	-0.25	-0.79	0.50	1.16	-0.78	-1.07	128.0 ± 13.7	-11.4
St. Pierre Bank (3Ps)	-0.11	0.96	-0.29	0.40	0.24	1.29	0.29	-0.75	0.25	-0.20	0.59	0.18	-2.96	-0.53	-1.19	-0.83	113.7 ± 8.5	-0.2
SE Shoal (3NO)	0.16	-0.40	-0.79	0.49	0.68	1.88	0.74	-0.81	-0.18	0.66	0.56	-2.96	-1.52	-0.67	-0.39	0.04	102.4 ± 13.5	0.5

Duration of Spring Bloom

Location	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013		
Hudson Strait (0B, 2G)	0.67	-1.02	-0.30	-1.19	-0.17	2.29	0.20	0.12	1.08	0.00	-0.99	-1.16	0.47	0.18	0.25	-0.15	158.5 ± 71.5	-6.7
N Labrador Shelf (2H)	0.34	-0.27	-0.66	1.30	-0.06	0.58	-0.43	-0.89	-0.95	0.24	2.48	-1.35	-0.79	-0.95	-0.30		55.3 ± 28.8	
Hamilton Bank (2J)	0.64	-1.03	0.40	2.29	0.68	-1.06	0.30	0.64	-0.28	-0.71	-1.41	0.19	-0.67	-0.81	-0.52	-0.96	54.8 ± 21.6	-37.9
St. Anthony Basin (3K)	0.68	-0.14	-1.08	-1.86	-0.63	-0.13	0.29	0.54	-0.27	-1.19	2.59	-0.29	0.86	-0.87	0.45	-1.47	49.5 ± 15.9	-47.0
NE Newfoundland Shelf (3KL)	0.79	1.36	0.36	-0.29	-0.58	-0.26	-0.03	-0.77	-0.52	-1.56	0.21	2.17	-0.90	-0.73	-0.40	-1.29	46.9 ± 18.9	-51.8
Avalon Channel (3L)	-0.13	0.07	-0.27	1.48	1.88	-0.55	0.77	1.54	-0.94	-1.11	-0.67	-0.66	-1.05	-1.02	-1.07	-0.82	41.6 ± 14.6	-28.7
Hibernia (3L)	0.40	-0.13	-0.13	0.35	2.06	1.17	1.10	-0.49	-1.01	-0.79	-1.13	-0.10	-1.29	-1.47	-0.60	2.05	44.9 ± 13.2	60.2
Flemish Pass (3L, 3M)	-0.35	-0.48	0.83	1.17	-0.89	-0.21	1.51	-0.61	-0.42	-1.02	-1.02	-0.16	2.29	-1.06	-1.29	-0.31	68.4 ± 29.4	-15.1
Flemish Cap (3M)						-0.14	0.74	0.99	-0.67	-0.83	-1.08	-0.72	1.73	-0.97	-1.14	-0.35	67.6 ± 38.1	-19.7
St. Pierre Bank (3Ps)	-0.63	-0.81	-0.42	-0.37	0.41	-0.56	0.07	-1.14	-0.97	-0.17	0.85	1.62	2.13	0.47	-1.21	-0.38	36.7 ± 15.2	-12.4
SE Shoal (3NO)	1.72	0.65	-0.58	-0.65	-0.04	-1.08	0.13	0.98	-0.45	-1.29	-0.17	1.72	-0.97	0.74	-1.19	-0.15	40.0 ± 11.0	-4.2

Initiation of Spring Bloom

Location	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013		
Hudson Strait (0B, 2G)	-0.51	1.02	0.90	0.95	0.11	-1.04	-0.77	-1.01	-1.87	0.64	0.34	1.54	-0.20	-0.31	-0.64	0.05	129.8 ± 28.9	1.2
N Labrador Shelf (2H)	-0.45	0.81	0.33	-0.86	0.84	-0.74	-0.97	-0.84	-0.35	2.29	-1.96	0.95	0.33	-0.04	-0.10		141.3 ± 42.6	
Hamilton Bank (2J)	-1.06	0.55	0.92	-0.76	1.15	1.02	-0.35	-1.01	-1.79	1.40	-0.23	0.62	-0.57	0.31	-0.53	0.55	123.9 ± 14.8	6.5
St. Anthony Basin (3K)	-0.44	-0.53	-0.45	0.53	0.49	1.94	0.57	-0.12	0.85	0.85	-2.16	-1.37	0.89	1.34	1.97	2.36	83.1 ± 18.0	50.8
NE Newfoundland Shelf (3KL)	-0.74	-1.68	-0.11	1.20	1.31	1.02	0.50	-0.14	-0.43	0.99	0.30	-1.56	-0.61	0.46	-0.24	0.91	97.0 ± 15.2	14.3
Avalon Channel (3L)	0.08	-1.62	-0.27	0.02	-0.64	2.06	-0.62	-1.76	0.84	0.71	1.22	-0.30	-0.38	0.74	0.43	0.71	88.3 ± 11.8	9.5
Hibernia (3L)	0.53	-0.94	-0.94	0.75	0.61	-0.32	-1.10	0.55	0.78	0.67	1.09	-0.81	-1.57	1.33	-0.01	-2.93	85.0 ± 9.9	-23.6
Flemish Pass (3L, 3M)	0.92	-1.17	0.15	0.83	1.58	1.81	-1.13	-0.21	-0.80	0.67	0.68	-0.17	-1.36	0.78	0.53	-0.56	96.7 ± 17.2	-9.9
Flemish Cap (3M)						1.49	-0.18	-1.48	0.09	0.46	0.79	0.15	-1.32	1.74	0.56	-0.41	94.3 ± 19.6	-8.5
St. Pierre Bank (3Ps)	0.28	1.02	0.06	0.43	-0.06	1.09	0.14	0.16	0.68	-0.83	-0.19	-0.76	-2.96	-0.58	-0.87	0.14	95.3 ± 13.9	2.1
SE Shoal (3NO)	-0.44	-0.55	-0.45	0.62	0.57	1.67	0.57	-0.34	0.07	0.99	0.52	-2.29	-0.93	0.48	0.15	0.08	82.5 ± 16.4	1.7

Figure 13. Annual standardized scorecard anomaly indices for peak timing, duration and initiation of the spring bloom across the Newfoundland and Labrador statistical sub-regions during 1998-2013. The standardized anomalies are the differences between the annual average for a given year and the long-term mean (1998-2010) divided by the standard deviation. The numbers on the right of the standardized anomalies are the 1998–2010 climatological means and standard deviations for the different ocean colour metrics; peak timing of the spring bloom in Julian day, duration of the bloom in days, and initiation of the spring bloom in Julian day, and the percent difference between the 2013 annual mean and the climatology mean. The numbers in the boxes are normalized anomalies. Negative anomalies for the timing indices (peak timing, duration and initiation) indicate earlier/shorter blooms while positive anomalies indicate the reverse. The statistical sub-regions are sorted from northern (top) to southern (bottom) boxes. Blank cells indicate the fitting routine could not be achieved. Data for Flemish Cap are not yet available during 1998-2002.

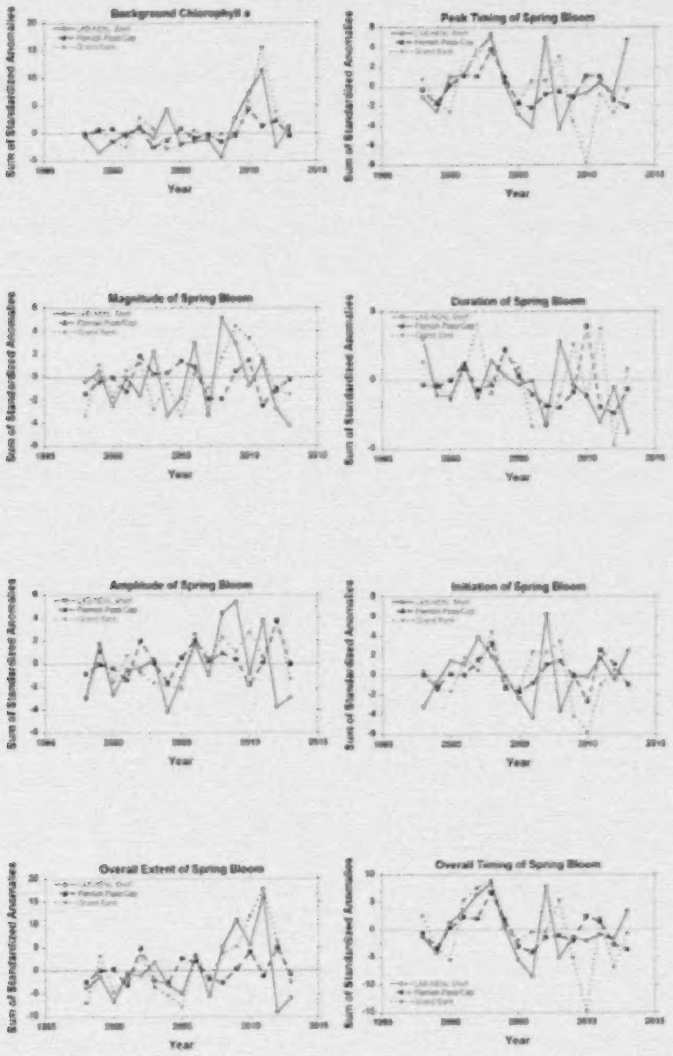

Figure 14. Composite annual anomalies across the Labrador and Newfoundland Shelf (LAB-NENL Shelf; Hudson Strait, Northern Labrador Shelf, Hamilton Bank, St. Anthony Basin, northeast Newfoundland Shelf), Flemish Pass and Flemish Cap, and Grand Bank (Avalon Channel, Hibernia, southeast Shoal, St. Pierre Bank) for satellite ocean colour indices during 1998-2013. The left panels show the extent of the spring production cycle while the right panels indicate the different timing indices. The bottom panels show the overall sums of annual anomalies for the extent and timing indices of the spring bloom. The summed standardized anomalies are the differences between the annual average for a given year and the long-term mean (1998-2010) divided by the standard deviation.

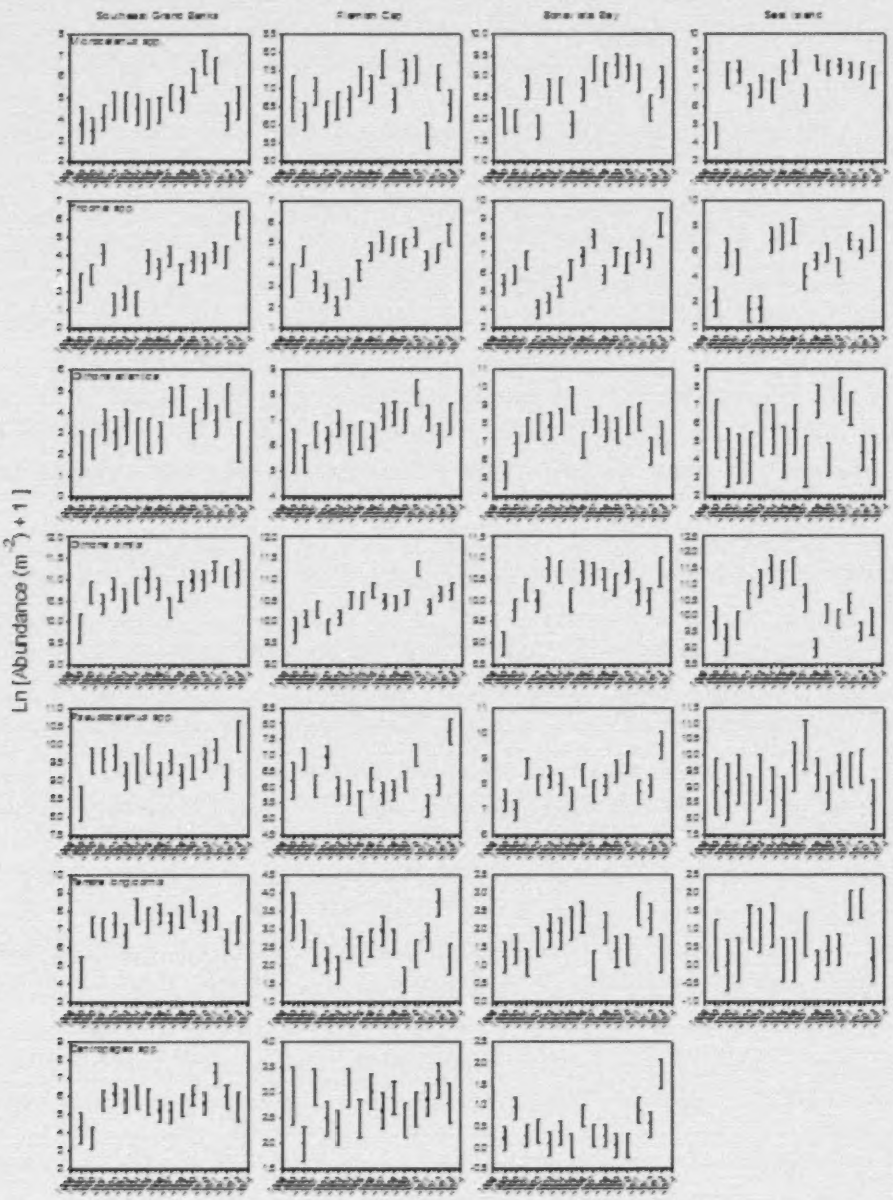

Figure 15. Seasonally-adjusted estimate of the mean abundance of small copepods from the oceanographic sections for the period 1999-2013. The error bars represent standard errors. Values from the Southeast Grand Banks are based on two occupations per year (spring, fall); values from the Flemish Cap and Bonavista sections are based on three occupations per year (spring, summer, fall); values from the Seal Island sections are based on one occupation per year (summer). The Southeast Grand Banks and Flemish Cap sections are in the southern ecoregion, while the Bonavista Bay and Seal Island sections are in the northern ecoregion.

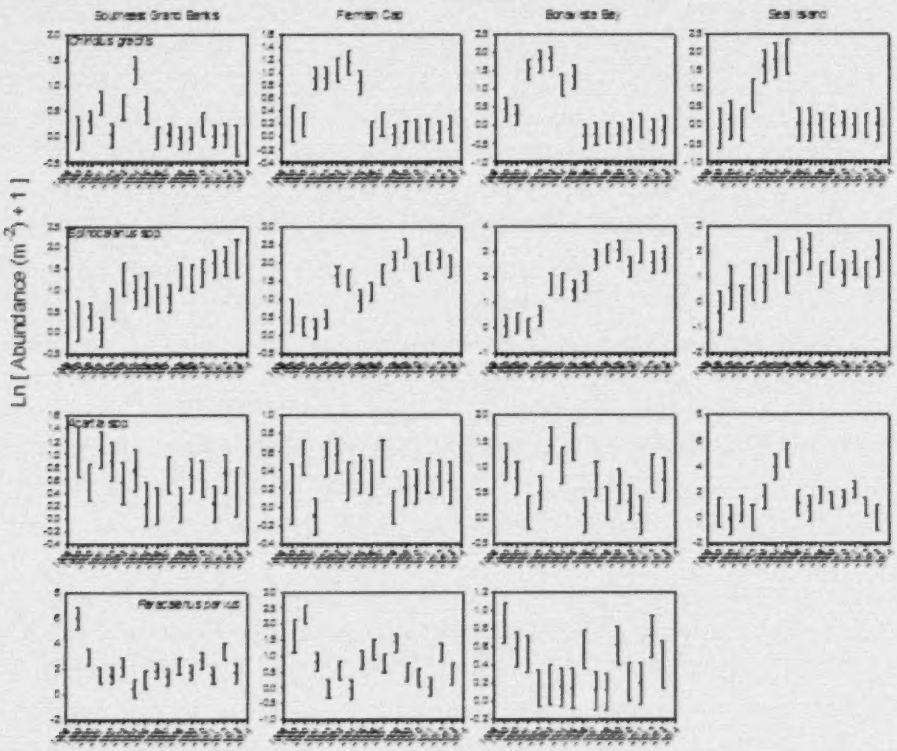

Figure 15. Continued.

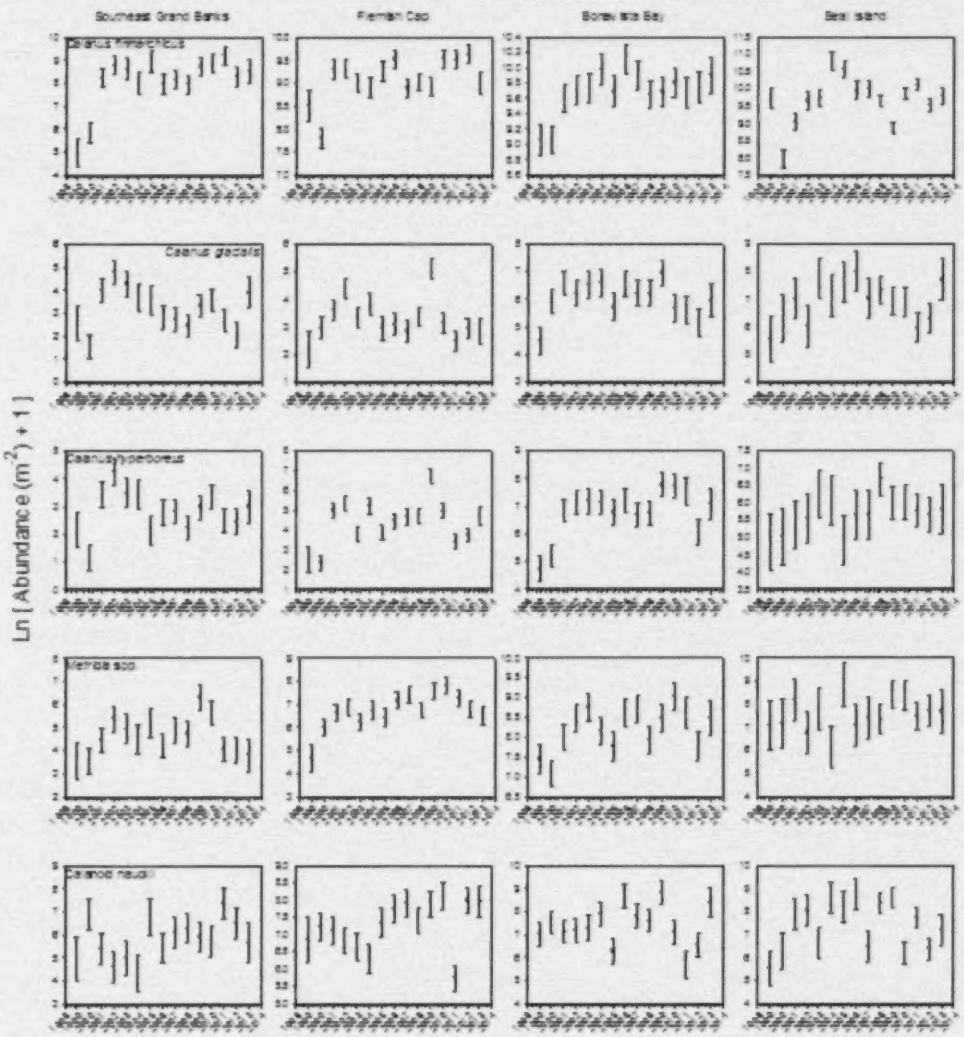

Figure 16. Seasonally-adjusted estimate of the mean abundance of large copepods from the oceanographic sections for the period 1999-2013. The error bars represent standard errors. Values from the Southeast Grand Banks are based on two occupations per year (spring, autumn); values from the Flemish Cap and Bonavista sections are based on three occupations per year (spring, summer, fall); values from the Seal Island section are based on one occupation per year (summer). The Southeast Grand Banks and Flemish Cap sections are in the southern ecoregion, while the Bonavista Bay and Seal Island sections are in the northern ecoregion.

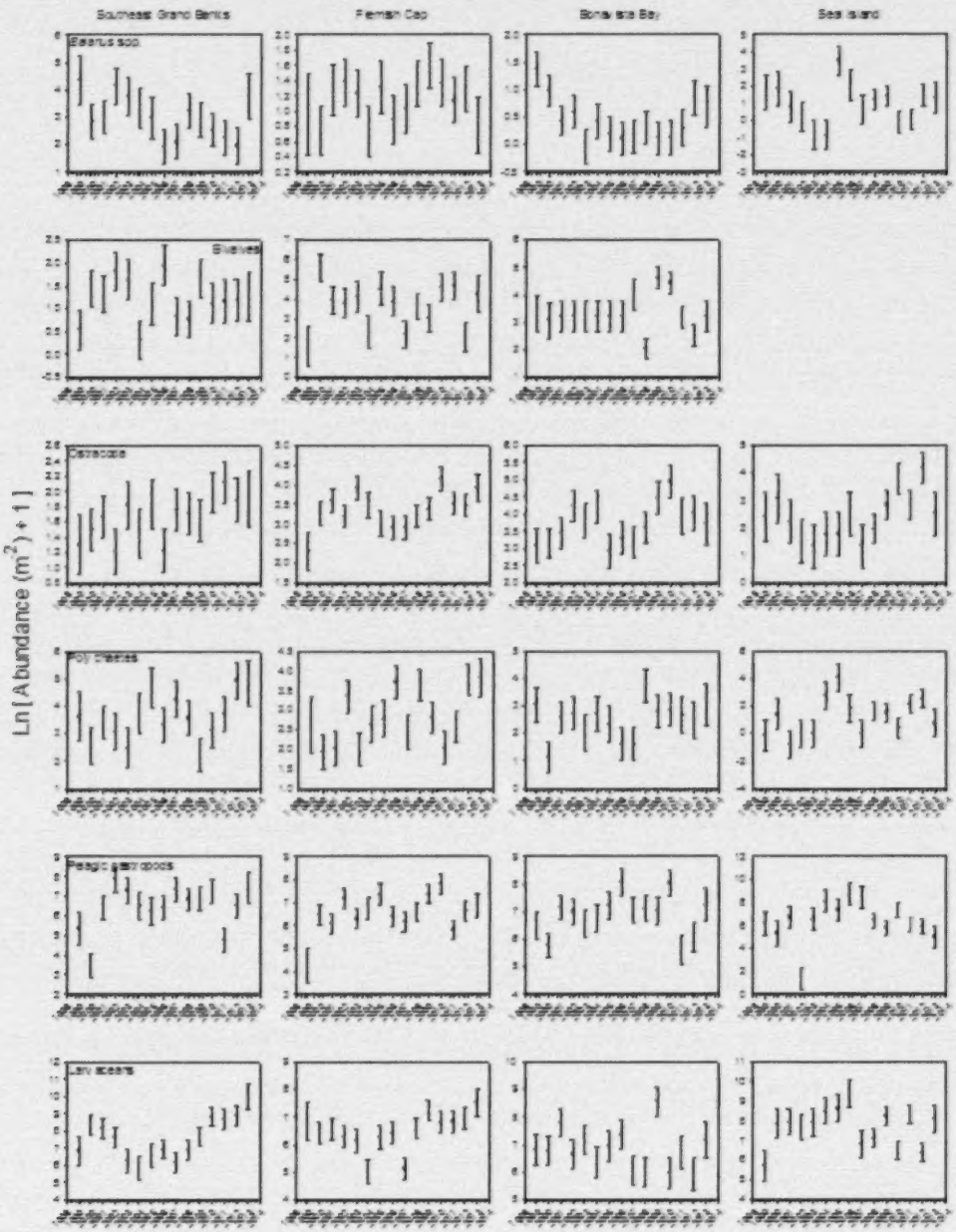

Figure 17. Seasonally-adjusted estimate of the mean abundance of meroplankton and other selected taxa from the oceanographic sections for the period 1999-2013. The error bars represent standard errors. Values from the Southeast Grand Banks are based on two occupations per year (spring, fall); values from the Flemish Cap and Bonavista sections are based on three occupations per year (spring, summer, fall); values from the Seal Island section are based on one occupation per year (summer). The Southeast Grand Banks and Flemish Cap sections are in the southern ecoregion, while the Bonavista Bay and Seal Island sections are in the northern ecoregion.

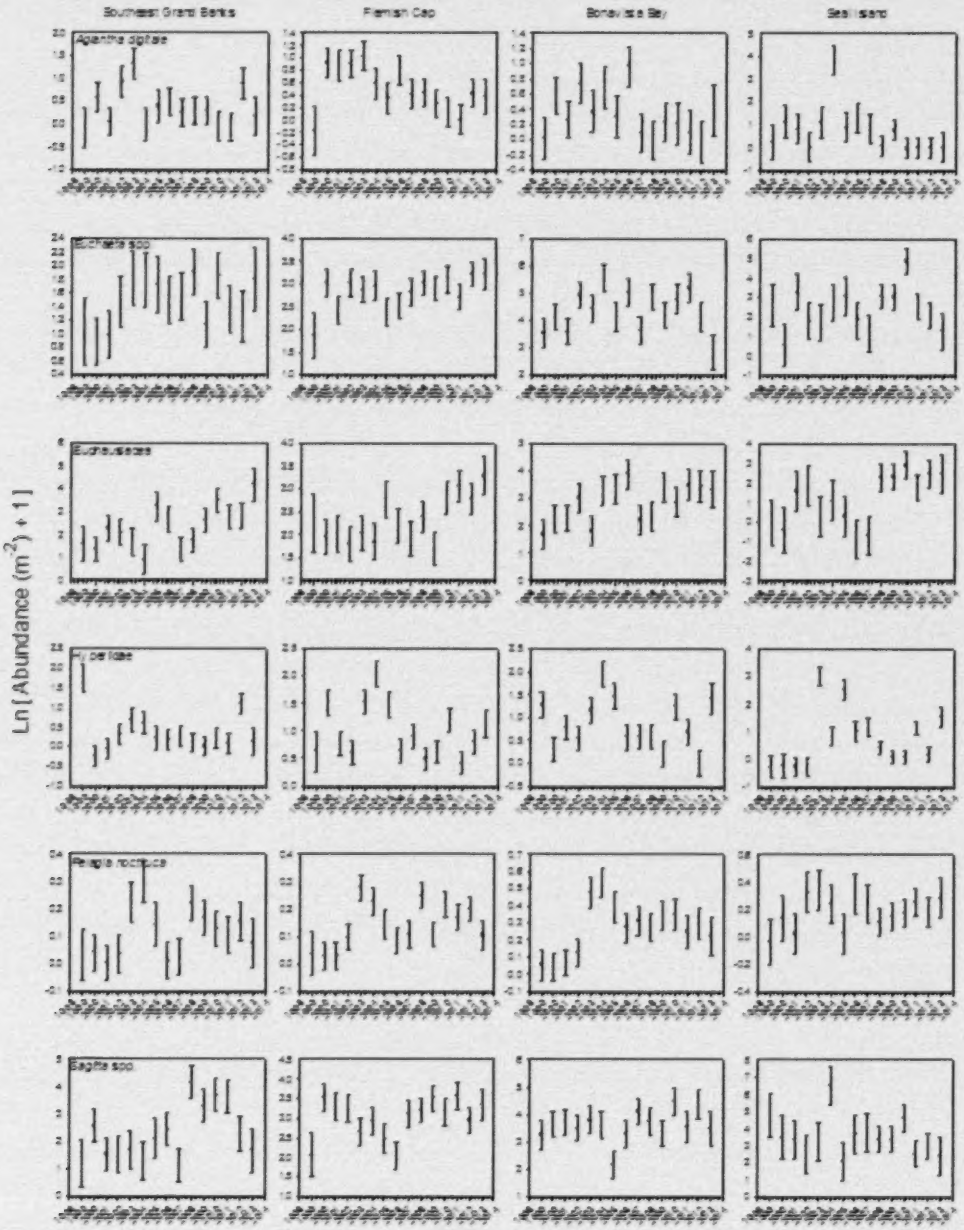

Figure 18. Seasonally-adjusted estimate of the mean abundance of carnivorous zooplankton from the oceanographic sections for the period 1999-2013. The error bars represent standard errors. Values from the Southeast Grand Banks are based on two occupations per year (spring, fall); values from the Flemish Cap and Bonavista sections are based on three occupations per year (spring, summer, fall); values from the Seal Island section are based on one occupation per year (summer). The Southeast Grand Banks and Flemish Cap sections are in the southern ecoregion, while the Bonavista Bay and Seal Island sections are in the northern ecoregion.

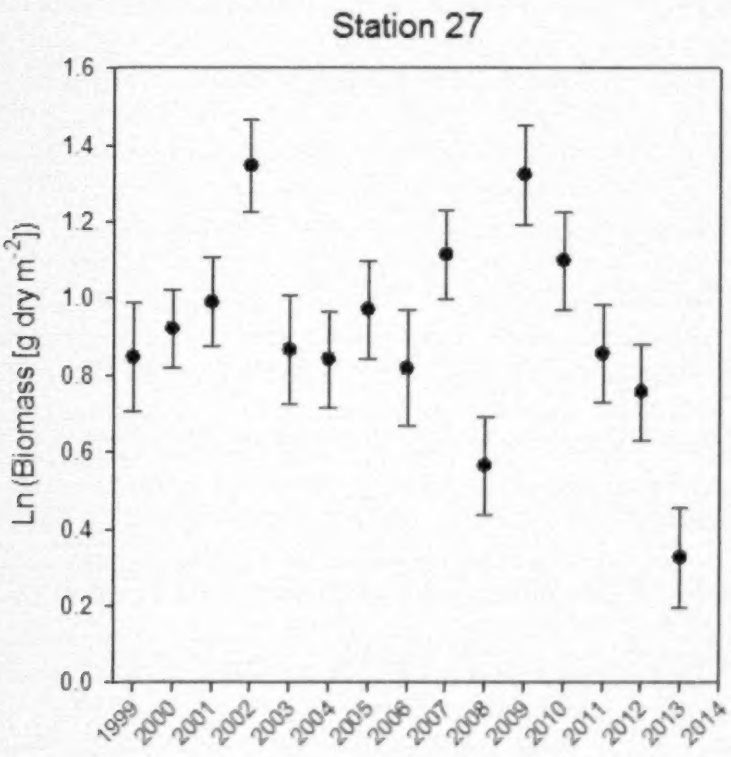

Figure 19. Seasonally-adjusted estimates of the mean biomass of 8 dominant copepod species from Station 27 for the period 1999-2013. The error bars represent standard errors.

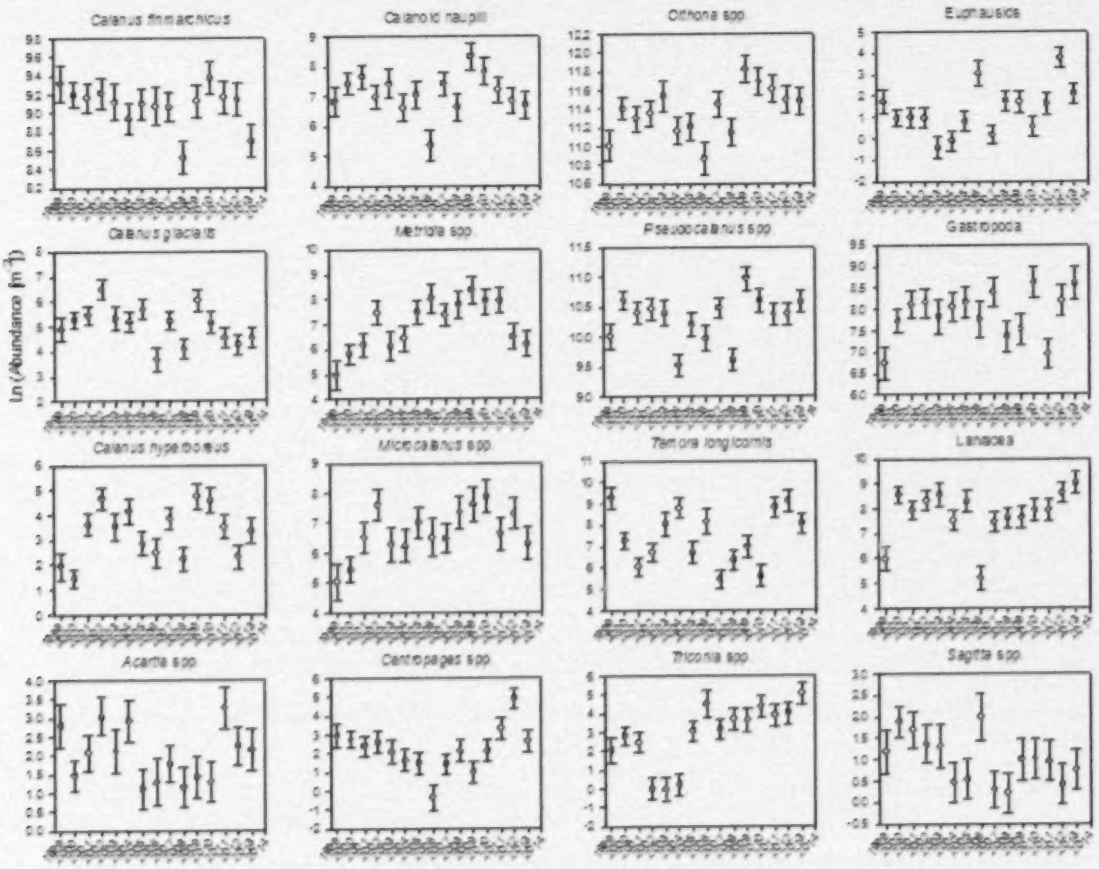

Figure 20. Seasonally-adjusted estimate of the mean abundance of twelve dominant zooplankton taxa from Station 27 for the period 1999-2013. The error bars represent standard errors.

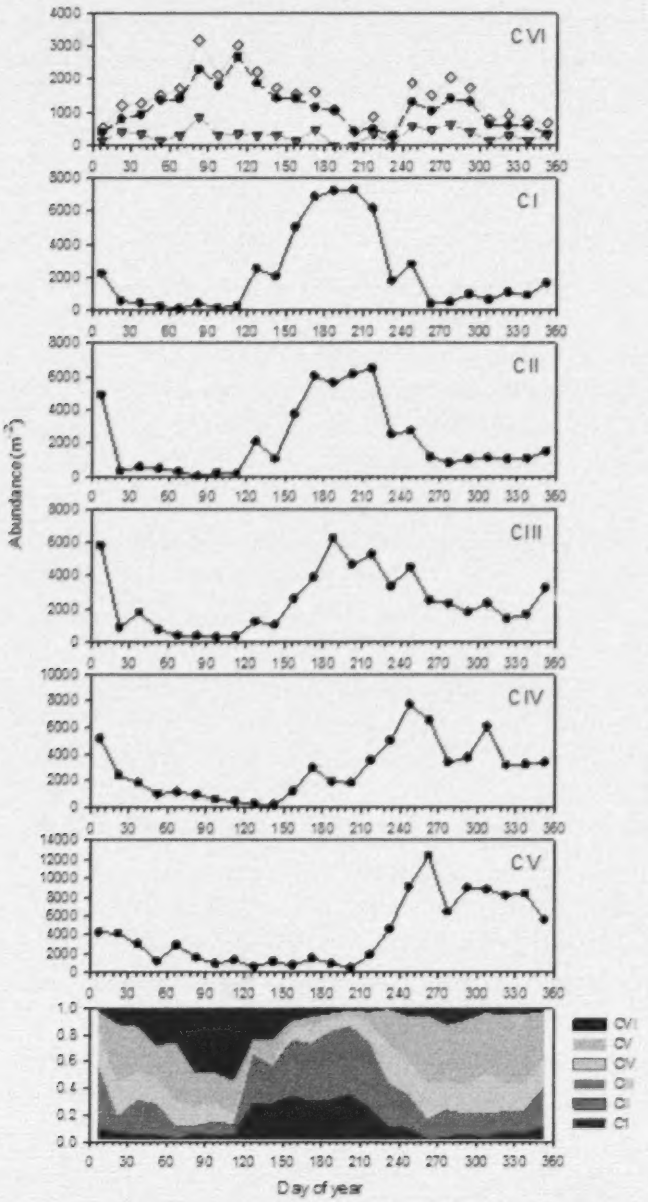

Figure 21. Climatological (2000-13) seasonal cycle in the abundance of adult (CVI; total – diamonds; females – black circles; males – inverted triangles) and copepodite stages (CI–CV) of Calanus finmarchicus at S27. The bottom panel represents the relative stage composition.

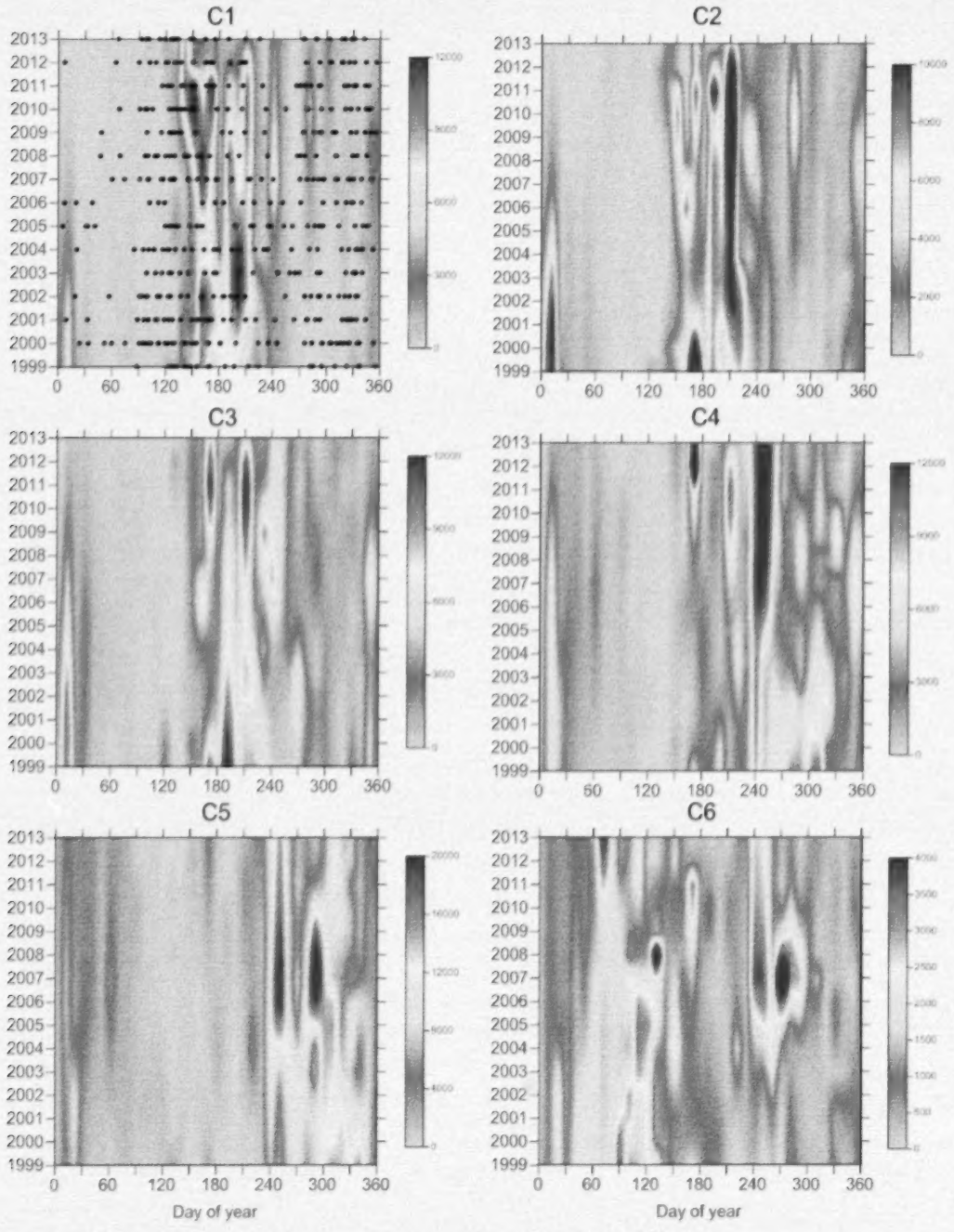

Figure 22. Seasonal cycle of abundance (number m^{-2}) of stage CI to CVI copepodites of Calanus finmarchicus for the period 1999-2013. The circles in the upper left panel reflect sampling dates.

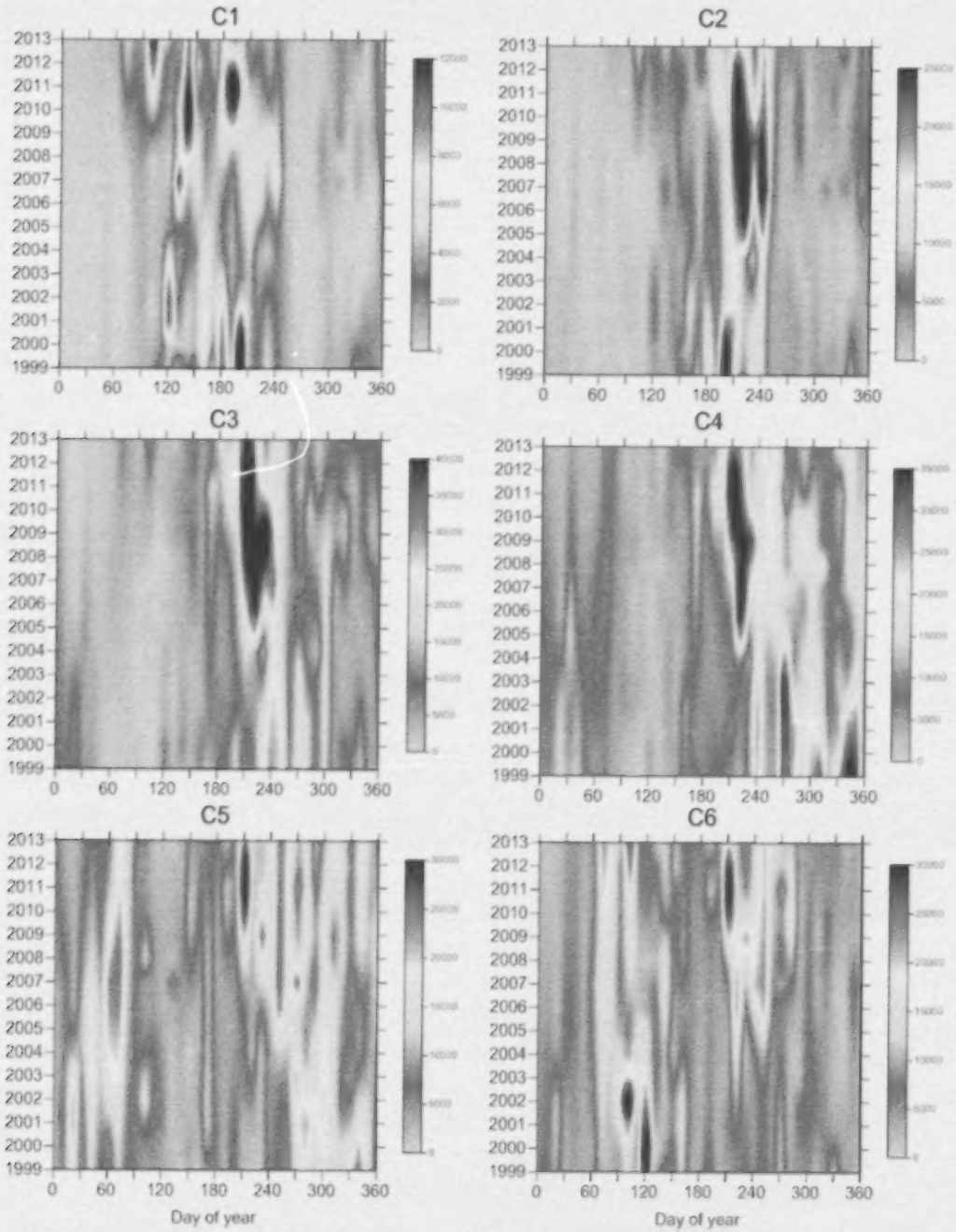

Figure 23. Seasonal cycle of abundance (number m^{-2}) of stage CI to CVI copepodites of Pseudocalanus sp. for the period 1999-2013.